THE XYZ's OF USING A SCOPE

Tektronix
Test and Measurement

CONTENTS

INTRODUCTION

When you watch an electrical engineer tackle a tough design project or a service engineer troubleshoot a stubborn problem, you'll see them find a scope, fit probes or cables, and start turning knobs and setting switches without ever seeming to glance at the front panel. To these experienced users, the oscilloscope is their most important tool, but their minds are focused on solving the problem, not on using the scope.

Making oscilloscope measurements is second nature to them. It can be for you too, but before you can duplicate the ease with which they use a scope, you will need to learn about the scope itself—both how it works and how to make it work for you.

This primer can help you learn enough about oscilloscopes and oscilloscope measurements that you will be able to use these tools quickly, easily and accurately. The text is divided into two parts.

Part I, in its first four sections, describes the functional parts of the scope and the controls associated with each function. It ends with a section on probes.

Part II builds on the knowledge and experience gained in Part I. The first section shows you typical signals you'll see on the oscilloscope screen and defines terms for parts of waveforms that are discussed. The next two sections cover safety and instrument set-up procedures. Then measurement techniques are described and exercises are included to help you practice a few basic measurements. You'll also find several examples of advanced techniques that can help you make more accurate and convenient measurements. The last section discusses oscilloscope performance and its effects on your measurements.

If possible, have a scope in front of you while working through each section—it's the best way both to learn and to apply your new knowledge. While the fundamentals apply to almost any scope, the exercises and illustrations use a specific instrument—the Tektronix 2225 Portable Oscilloscope.

The 2225 is a dual-channel, 50-MHz portable designed as an easy-to-use, lightweight, general-purpose oscilloscope. It has alternate magnification for detailed signal analysis as well as an exceptionally low-noise vertical system that can operate at 500 μV/div sensitivity.

If you have comments or questions about the material in this primer, please feel free to write:

Oscilloscope Primer
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You may also call the Tektronix National Marketing Center toll free: **1-800-426-2200.**

PART I. SCOPES, CONTROLS, AND PROBES

You can measure almost anything with the two-dimensional graph drawn by an oscilloscope. In most applications the scope shows you a graph of voltage (on the vertical axis) versus time (on the horizontal axis). This general-purpose display presents far more information than is available from other test and measurement instruments such as frequency counters and multimeters. For example, with a scope you can find out how much of a signal is direct (dc), how much is alternating (ac), how much is noise (and whether or not the noise is changing with time), what the frequency of the signal is, and more. With a scope you can see everything at once rather than having to make many separate tests.

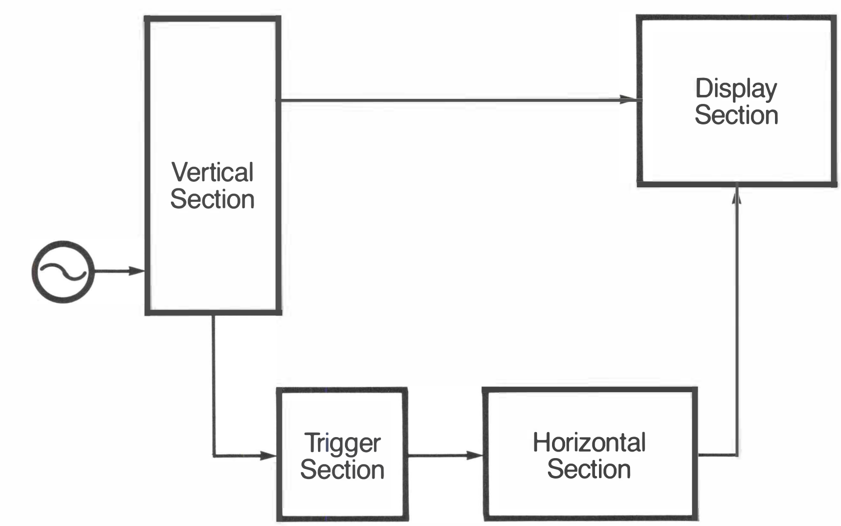


Figure 1. THE BASIC OSCILLOSCOPE in its most general form has four functional sections (or systems): vertical, horizontal, trigger, and display. The display system is also sometimes called the *crt* (cathode-ray tube) *section*.

Most electrical signals can be easily connected to the scope with either probes or cables. Transducers, which change one kind of energy into another, are available for measuring nonelectrical phenomena. Speakers and microphones are two examples of transducers. A speaker converts electrical energy to sound waves and a microphone converts sound to electricity. Other typical transducers can transform mechanical stress, pressure, light, or heat into electrical signals.

Given the proper transducer, your test and measurement capabilities with an oscilloscope are almost endless.

Making measurements is easier if you understand the basics of how a scope works. You can think of the instrument in terms of the functional blocks illustrated in Figure 1—vertical, trigger, horizontal, and display.

The vertical system controls the vertical axis of the graph. Any time the electron beam that draws the graph moves up or down, it does so under control of the ver-

tical system. The horizontal system controls the left-to-right movement of the beam. The trigger system determines when the oscilloscope begins drawing by starting the horizontal sweep across the screen. And the display system contains the cathode-ray tube (crt), on which the graph is drawn.

Part I of this primer is divided into five sections—one for each of the four functional systems and one for probes. In each section, the controls are identified, and you can locate them on the two-page foldout illustration of a Tektronix 2225 Oscilloscope front panel at the back of the primer. The controls and their functions described, and at the end of the section, there are hands-on exercises using those controls.

The last section in this part describes probes. When you finish reading Part I, you'll be ready to make fast and accurate oscilloscope measurements.

Before you turn on your scope, remember that you should always be careful when working with electrical equipment. Observe all safety precautions in your test and measurement operations. Use the proper power cord and correct fuse. Always plug the power cord of the scope into a properly wired receptacle before connecting your probes or turning on the scope. And don't remove the covers and panels of the scope.

Now fold out the photograph of the Tektronix 2225 Oscilloscope at the back of this primer so that you can see it as you read. Follow Exercise 1 to initialize the scope controls you will be using. *Initialize* means to set in standard positions. These standard settings are necessary so that, as you follow the directions on these pages, you'll see the same display on your scope crt as the displays pictured and described here.

Exercise 1. INITIALIZING THE SCOPE

Use the foldout at the back of this primer to locate the controls described here.

1. *DISPLAY SYSTEM CONTROLS: Set the INTENSITY control at midrange (about halfway from either stop). Turn the FOCUS knob completely clockwise.*

2. *VERTICAL SYSTEM CONTROLS: Turn the channel 1 POSITION control completely counterclockwise. Make sure the left VERTICAL MODE switch is set to CH 1. Move both VOLTS/DIV switches to the least sensitive setting (5V) by rotating them completely counterclockwise. Verify that both center CAL controls are locked in their detents (completely clockwise) and are pushed in (X1 vertical magnification). Set both input coupling switches (located below the VOLTS/DIV switches) to GND.*

3. *HORIZONTAL SYSTEM CONTROLS: Set the HORIZONTAL MODE switch to X1. Rotate the SEC/DIV switch to 0.5 ms (0.5 millisecond per division). Make sure the variable (CAL) control in the center of the SEC/DIV switch is locked in its detent (fully clockwise).*

4. *TRIGGER SYSTEM CONTROLS: Make sure the HOLDOFF control is rotated to MIN (completely counterclockwise). Set the TRIGGER MODE switch to P-P AUTO. Move the left SOURCE switch to CH 1.*

5. *Finally, verify that the LINE VOLTAGE SELECTOR switch on the rear panel is set for the proper nominal voltage source and that the proper fuse is installed. Then plug the scope into a properly grounded outlet and turn it on by pressing in the POWER pushbutton. Let the scope warm up for about five minutes—then you're ready to go!*

THE DISPLAY SYSTEM

The oscilloscope draws a graph by moving an electron beam across a phosphor coating on the inside of the crt. The result is a glow, which, for a short time afterwards, traces the path of the beam. A grid of lines etched on the inside of the faceplate serves as the reference for measurements; this is the graticule shown in Figure 2.

Common controls for display systems include intensity and focus; some oscilloscopes also have a beam finder and trace rotation controls. At the top of the 2225, directly to the right of the crt, is the intensity control, labeled INTENSITY. Then come the beam finder (BEAM FIND), FOCUS, and TRACE ROTATION controls. These controls are described next, and their locations on the Tektronix 2225 are shown on the foldout at the back of this primer.

Intensity

The INTENSITY control adjusts the brightness of the trace. It is necessary because you use a scope in different ambient-light conditions and with many kinds of signals. For instance, on square waves, because the slower horizontal segments look brighter than the faster vertical segments, you will probably want to turn up the intensity to make the fainter parts of the waveform easier to see.

The INTENSITY control is also useful because the intensity of a trace depends on two factors: how bright the beam is and how long it is on screen. As you select different sweep speeds (a sweep is one movement of the electron beam across the scope screen) with the SEC/DIV switch, the beam on and beam off times change—that is, the beam has either more or less time to excite the phosphor.

Beam Finder

For convenience, the beam finder lets you locate the electron beam when it is off-screen. When you push the BEAM FIND button, you reduce the vertical and horizontal deflection voltages (more about deflection voltages later) and override the INTENSITY control so that the beam always appears within the 80-by-100 millimeter screen. When you see the quadrant of the screen in which the beam appears, you'll know which way to turn the HORIZONTAL and VERTICAL POSITION controls to reposition the trace. If you inadvertantly turned down the display intensity, you will still locate the trace, since intensity is automatically increased while BEAM FIND is pressed.

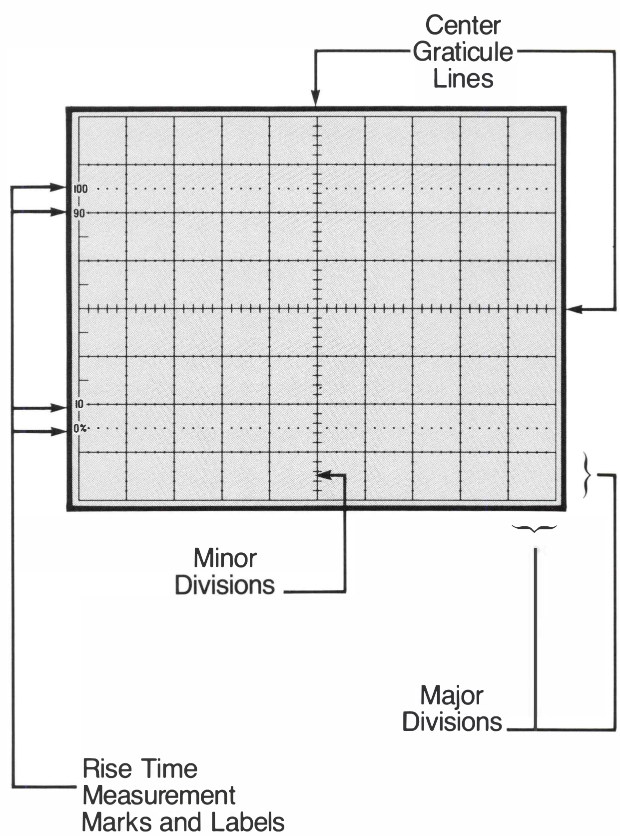


Figure 2. THE GRATICULE is a grid of lines typically etched or silk-screened on the inside of the crt faceplate. Putting the graticule inside—on the same plane as the trace drawn by the electron beam—eliminates measurement inaccuracies called *parallax errors*. Parallax error occurs when the trace and the graticule are on different planes and the observer shifts slightly from the direct line of sight. Though different-sized crt's may be used, graticules are usually laid out in an 8-by-10 pattern. Each of the 11 vertical and 9 horizontal lines block off major divisions (also simply called *divisions*) of the screen. Labeling on the scope controls always refers to major divisions. The tick marks on each of the graticule lines represent minor divisions or subdivisions. Since scopes are often used for rise time measurements, 2200-Series scope graticules include special markings to aid in making rise-time measurements. There are dashed lines for 0% and 100% levels and labeled graticule lines for the 10% and 90% points (where rise time is measured).

Focus

The electron beam of the scope is focused on the crt faceplate by an electrical grid within the tube. The FOCUS control adjusts that grid for optimum trace focus. On a 2200-Series scope, the focus circuit maintains focus settings over most intensities and sweep speeds.

Trace Rotation

Another display control on the front panel of a 2200-Series instrument is TRACE ROTATION. This adjustment lets you electrically align the horizontal deflection of the trace with the fixed crt graticule. To avoid accidental misalignments when the scope is in use, the control is recessed and must be adjusted with an adjustment tool or a screwdriver.

If this seems like a calibration item that should be adjusted once and then forgotten, it is—for most oscilloscope applications. But the earth's magnetic field affects trace alignment, and when a scope is used in many different positions—as a service scope will be—it's very handy to have a front-panel trace-rotation adjustment.

Using the Display Controls

The display system and its controls are shown as functional blocks in Figure 3. Use Exercise 2 to review the display controls.

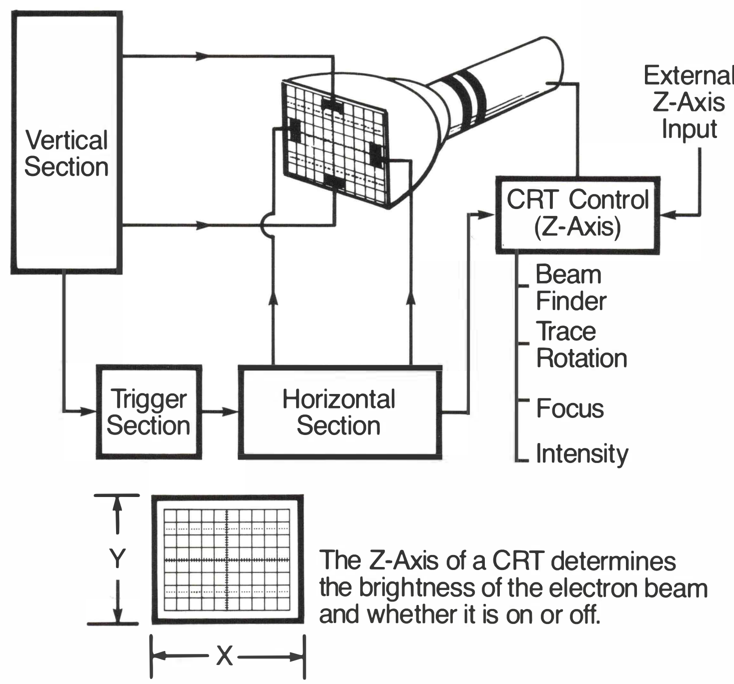


Figure 3. THE DISPLAY SYSTEM consists of the Z-axis, cathode-ray tube, and controls. To draw the graph of your measurements, the vertical system takes the input signal and supplies the Y-axis coordinates and the horizontal system supplies the X-axis coordinates. The trigger system takes input-signal information from the vertical system and uses it to start the horizontal sweep. The horizontal system also controls the Z-axis, which determines whether the electron beam (intensity) is turned on or *blanked* (off).

Exercise 2. DISPLAY SYSTEM CONTROLS

In Exercise 1 you initialized your scope and turned on the power. Now find the display system controls labeled on the foldout illustration at the back of the primer and use them as you follow these instructions.

1. *BEAM FIND: Locate the position of the electron beam by pushing and holding in the BEAM FIND button; then use the channel 1 VERTICAL POSITION knob to position the trace on the center horizontal graticule line. Keep BEAM FIND pressed in and use the HORIZONTAL POSITION control to center the trace. Then release the beam finder.*

2. *FOCUS: The trace you have on the screen now should be out of focus. Make it as sharp as possible using the FOCUS control.*

3. *INTENSITY: Set the brightness so that you get a good display.*

4. *VERTICAL POSITION: Now use the VERTICAL POSITION control to line up the trace with the center horizontal graticule line.*

5. *TRACE ROTATION: Use a small screwdriver to rotate the TRACE ROTATION control in both directions. Notice that the trace appears to revolve clockwise and counterclockwise. When you finish, align the trace so that it is parallel to the horizontal graticule line closest to it. After aligning the trace, you may have to use the VERTICAL POSITION control again to set the trace on the graticule line.*

You have now used all the scope's display-system controls. If, at the end of a chapter you don't plan to continue right away, be sure to turn off your scope.

THE VERTICAL SYSTEM

Your scope's vertical system supplies the display system with the vertical—or Y-axis—information for the graph on the crt screen. The vertical system takes the input signals, develops *deflection voltages*, then uses the deflection voltages to control—that is, deflect—the crt electron beam.

The vertical system also gives you a choice of how you connect the input signals (called *coupling*, described below). And it provides internal signals for the trigger circuit, which is described in a later section. Figure 4 schematically illustrates the vertical system.

The set of dual vertical-system controls—see the foldout at the back of this primer for their locations—include the POSITION controls, the VOLTS/DIV sensitivity controls, and the input coupling switches. Because the 2225 has two channels, there are one set of these switches and a POSITION control for each channel. There are also a trace-separation control (TRACE SEP) and three mode switches. The left MODE switch lets you select channel 1, channel 2, or both signals for display; the center switch lets you select either an uninverted or inverted channel 2 display; and the right MODE switch lets you select a display that algebraically combines channel 1 and channel 2 (ADD), an alternated display (ALT), or a chopped display (CHOP).

For the exercises in this section, you'll need a 10X probe like the Tektronix P6103 10X Probe supplied with every 2225 Oscilloscope.

Vertical Position

The vertical POSITION controls let you place the trace exactly where you want it on the screen. The position control for each channel changes the vertical placement of its respective trace.

Input Coupling

The input coupling switch for each vertical channel lets you control how the input signal is coupled to the vertical channel. When DC (the abbreviation stands for *direct current*) input coupling is selected, you see all of an input signal. With AC (*alternating current*) coupling, the constant (static) signal components are blocked and only the alternating (dynamic) components of the input signal reach the channel. For an illustration of the differences, see Figure 5.

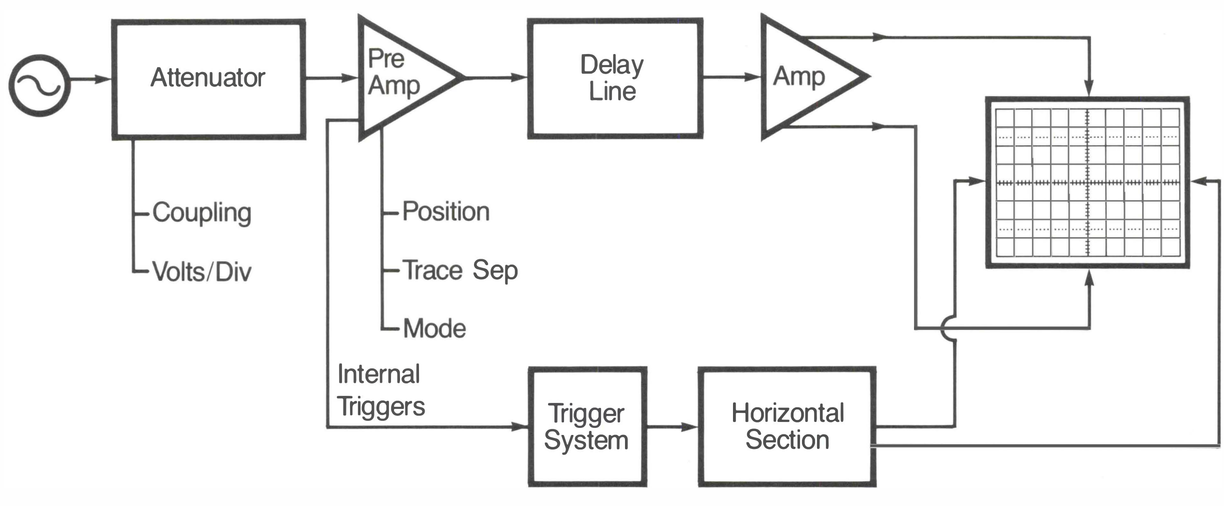


Figure 4. THE VERTICAL SYSTEM of a Tektronix 2200-Series scope consists of two identical channels, though only one is shown in the drawing. Each channel has circuitry to couple an input signal to that channel, attenuate the signal (that is, reduce it) preamplify it, delay it, and finally amplify the signal for use by the display system. The delay line lets you see the beginning (or leading edge) of a waveform even when the scope is triggering on it.

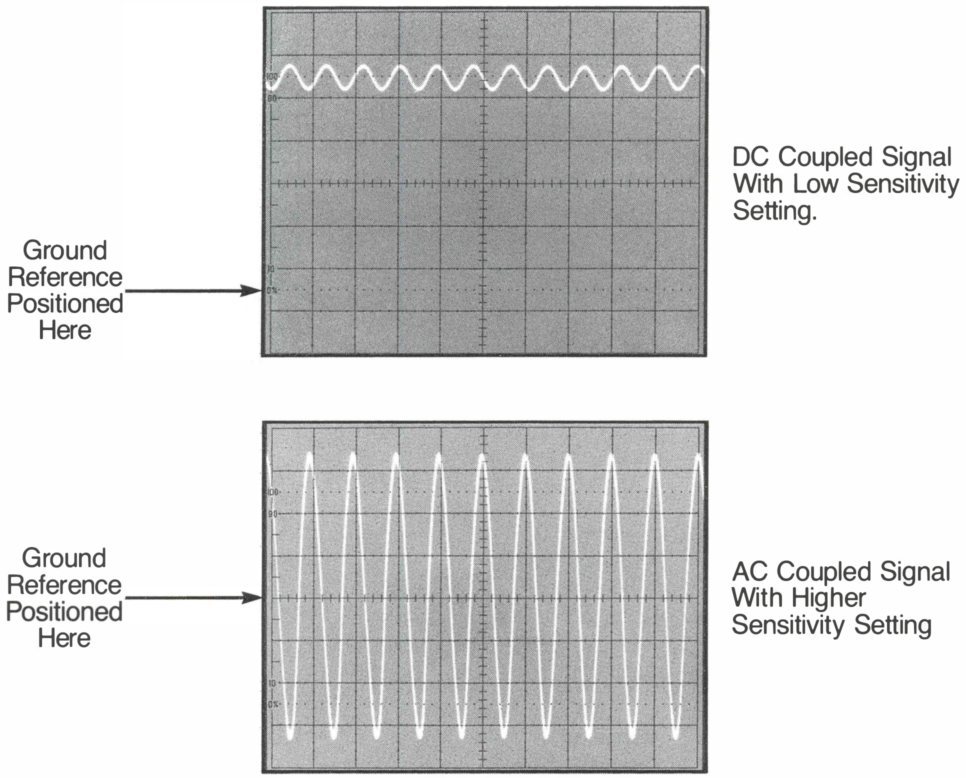


Figure 5. VERTICAL CHANNEL INPUT COUPLING CONTROLS let you choose AC and DC input coupling and ground (GND). Using DC coupling connects the entire input signal to the vertical channel. AC coupling blocks constant (static) signal components and only connects alternating (dynamic) components to the vertical channel. The GND position disconnects the input signal from the vertical system. And when P-P AUTO triggering mode is set, the display is a baseline trace indicating chassis ground or zero volts. The position of the trace on the screen in this mode is the ground reference level. Switching from DC to GND and back is a handy way of measuring signal voltage levels with respect to chassis ground. Using the GND position does not ground the signal in the circuit you're probing. The AC coupling setting is handy when the entire signal (alternating plus constant components) is too large for the VOLTS/DIV settings, as shown in the top photo. Eliminating the constant component lets you look at the alternating signal with a more convenient VOLTS/DIV setting, as shown in the bottom photo.

The middle position of the coupling switches is marked GND, for *ground*. This setting disconnects the input signal from the vertical system. And when P-P AUTO triggering mode is set, the display shows a baseline trace indicating chassis ground or zero volts. The position of the trace on the screen in this mode is the ground reference level. Switching from DC to GND and back is a handy way of measuring signal voltage levels with respect to chassis ground. Using the GND position does not ground the signal in the circuit you're probing.

Vertical Sensitivity

The VOLTS/DIV switch determines the sensitivity of each vertical channel. The ability to select a range of sensitivities extends the depth of possible applications. A multipurpose scope can accurately display a broad range of signal levels, from millivolts to many volts. With a maximum sensitivity of 500 μV (0.5 mV) per division, the Tektronix 2225 Oscilloscope is four to ten times more sensitive than other comparable instruments.

The slash (/) in VOLTS/DIV stands for *per*, and each setting of this switch is a scale factor. For example, a setting of 20 mV means 20 millivolts per division. Using the VOLTS/DIV switch to change sensitivity also changes the *scale factor*, which is the value of each major division on the screen. Each setting of the switch is marked with a number that represents the scale factor for that channel. To illustrate, suppose the VOLTS/DIV setting is 5 V; then each of the eight vertical major divisions represents 5 volts, and the entire screen can show 40 volts from bottom to top. With a setting of 500 μV per division, the screen can display 4 millivolts from top to bottom.

Vertical Magnification

The 500 μV per division sensitivity of the 2225 is achieved by using an additional gain (or amplifier) stage. It is activated by pulling out the VOLTS/DIV variable (CAL) knob and it increases the selected sensitivity by a factor of 10. Each channel has its own independent amplifier that operates with all VOLTS/DIV settings. When the X10 vertical magnification feature is selected, bandwidth is reduced to 5 MHz. Thus it can be used as a bandwidth-limiting mode when high-frequency noise is present on the input signal.

Probe Scale Factor

The probe you use influences the scale factor. On the front panel, next to each VOLTS/DIV switch, notice the two bracketed areas labeled 1X and 10X PROBE. The right area shows the scale factor for a standard 10X probe. The left area shows the scale factor for a 1X probe.

Variable VOLTS/DIV

The CAL control in the center of each VOLTS/DIV switch provides a continuously variable change in the scale factor—up to more than 2.5 times the VOLTS/DIV setting. This control is used most commonly to align waveforms vertically with the 0% and 100% graticule lines when making risetime measurements. The variable sensitivity control is also useful for making quick amplitude comparisons of a series of signals. You could, for example, take a known signal of almost any amplitude and use the CAL control to make sure the waveform fits exactly between major division graticule lines. Then, using the same vertical channel to look at other signals, you could quickly see whether later signals had the same amplitude.

Channel 2 Inversion

For differential measurements (described in Part II) you can invert the polarity of the channel 2 signal by using the middle VERTICAL MODE switch. When the switch is set to the right (CH 2 INVERT), the channel 2 signal is inverted; when it is set to the left (NORM), both channels have the same polarity.

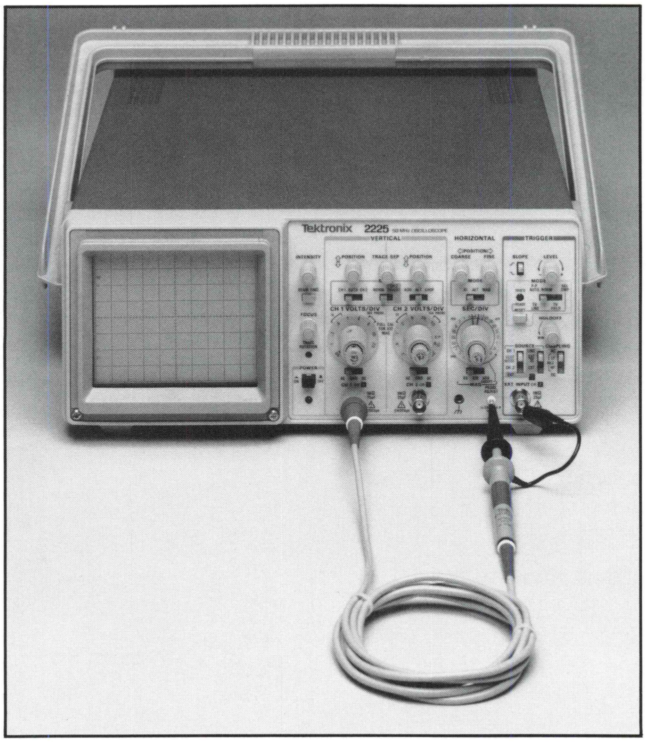


Figure 6. THE TEKTRONIX P6103 10X PROBE connects to the BNC connector of either channel 1 (shown) or channel 2. Although not shown in the photo, the probe's ground strap is usually connected to the ground of the circuit you are working on. The PROBE ADJUST terminal is located at the bottom of the HORIZONTAL section on the front panel.

Vertical Operating Modes

Scopes become more useful as the number of vertical display modes increases. You have several display choices with your Tektronix 2225 Oscilloscope. These modes are controlled by the left and right VERTICAL MODE switches. With these two switches, you can select channel 1 alone, channel 2 alone, both channels in either alternated or chopped mode, and both channels algebraically summed.

To display only channel 1, set the left switch to CH 1; to display only channel 2, set it to CH 2.

To see both channels in the alternated mode, set the left switch to BOTH and the right switch to ALT. This causes each channel to be drawn alternately—the scope completes first one sweep on channel 1, then one sweep on channel 2, and then repeats. This mode is used with medium to fast signals—when the SEC/DIV switch is set to 0.5 ms or faster.

To display both channels in a chopped mode, set the left switch to BOTH and the right switch to CHOP. Now the scope will draw small parts of each signal by switching back and forth between them. The switching rate is so fast that your eyes naturally fill in the gaps, and the waveform looks whole. This mode is typically used with slow signals requiring sweep speeds of 1 ms per division and slower.

Both chopped and alternated modes are provided so that you can look at two signals at any sweep speed. The ALT mode first draws one trace then the other, not both at the same time. This works well at faster sweep speeds, when your eyes can't detect the alternating action. To see two signals (simultaneously) at slower sweep speeds, use the CHOP mode.

To see the two input signals displayed as one waveform, set the left switch to BOTH and the right switch to ADD. This gives you an algebraically combined signal—either channel 1 + channel 2, or differentially combined (channel 1 — channel 2), when channel 2 is inverted.

Sweep Separation

The 2225 alternate-magnification scope also has a sweep separation control. Labelled TRACE SEP, it's used to change the vertical positon of a horizontally magnified trace with respect to the unmagnified trace of the same signal. Using the TRACE SEP control in conjunction with the vertical POSITION controls lets you place all four traces (the magnified and unmagnified traces for each of two channels) on the screen so that they don't overlap. Horizontal magnification is discussed in the next section.

Using the Vertical Controls

Before using the vertical system controls, make sure all the front-panel controls are positioned where you left them at the end of the last chapter:

Display
- INTENSITY and FOCUS: Bright, crisp trace

Vertical
- POSITION (Channel 1): Fully counterclockwise
- MODE: CH 1
- VOLTS/DIV (both): 50 V (10X PROBE)
- VOLTS/DIV Variable (both): CAL detent (fully clock wise) and pressed in (no vertical magnification)
- Input Coupling (both): GND

Horizontal
- MODE: X1
- SEC/DIV: 0.5 ms
- SEC/DIV Variable: CAL detent (fully clockwise)

Trigger
- MODE: P-P AUTO
- HOLDOFF: MIN (fully counter clockwise)
- SOURCE: CH 1

Now connect your 10X probe to the CH 1 BNC connector on the front panel of your scope. (BNC means *bayonet Neill-Concelman* and is named for Paul Neill, who developed the N-Series connectors at Bell Labs, and Carl Concelman, who developed the C-Series connectors.)

Attach the tip of the probe to the PROBE ADJUST terminal. Probes come with an alligator-clip ground strap for grounding the probe to the circuit under test. Clip the ground lead onto the collar of the CH 2 BNC connector as shown in Figure 6.

Using the callouts on the foldout figure at the back of this primer to remind yourself of control locations, follow the directions in Exercise 3 to review the vertical system controls.

Exercise 3. VERTICAL SYSTEM CONTROLS

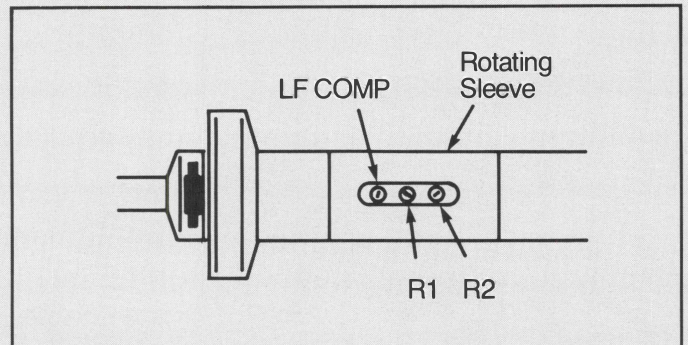
Compensating Your Probe

1. *Turn on the scope and turn the CH 1 VOLTS/DIV switch clockwise to 0.5 V. The P6103 is a X10 probe, so use the VOLTS/DIV readout to the right (labeled 10X PROBE).*

2. *Switch channel 1 input coupling to AC.*

3. *If the signal on the screen isn't steady, turn the trigger LEVEL control until the signal stops moving and the triggered light (labeled TRIG'D) is illumined. If needed, use the FOCUS and INTENSITY controls to adjust signal sharpness and brightness.*

4. *Next, compensate the probe using the screwdriver adjustment in the probe head. To expose the adjustment screw, rotate the sleeve on the probe head until you see the low-frequency compensating (LF COMP) capacitor. Then, while observing the screen display, use a plastic adjustment tool to turn the LF COMP capacitor until the tops and bottoms of the square wave are flat (see photograph on page 28). You'll find more information about probes starting on page 22.*



Location of compensation adjustments on the Tektronix P6103 probe.

Controlling Vertical Sensitivity

1. *The probe adjustment signal is an approximately 1-kHz square wave with about 0.5 V amplitude. The scale factor for channel 1 is currently set at a half-volt per division. At this setting every major division on the screen represents half a volt. Use the channel 1 POSITION control to line up the bottom edge of the waveform with the center horizontal graticule line. Notice that the top of the square wave is just touching the next major division line, which demonstrates that the probe-adjustment signal is indeed about 0.5 V.*

2. *Turn the VOLTS/DIV switch clockwise two more stops. The channel 1 scale factor is now 0.1 volts per division (with a 10X probe), and the signal—still 0.5 V—is now about five major divisions in amplitude.*

3. *Turn the VOLTS/DIV variable (CAL) control counterclockwise out of its detent and notice what happens. When you've turned it fully counterclockwise, the signal should be less than two major divisions in amplitude, because the scale factor was reduced by at least 2.5 times. Now return the variable (CAL) control to its detent (fully clockwise).*

4. *Set the channel 1 VOLTS/DIV switch to 5 V and pull out (towards you) the CAL-X10 knob. Observe that the displayed waveform is one division in amplitude, indicating that vertical sensitivity is now back to 0.5 V per division. Push in the CAL X10 knob and return the CH 1 VOLTS/DIV switch to 0.1 V.*

Coupling the Signal

1. *Switch the channel 1 input coupling to GND and position the trace on the center horizontal graticule line. Switch back to AC coupling and note that the*

waveform remains centered on the screen. Move the CH 1 VOLTS/DIV switch to 0.5 V and notice that the waveform is still centered around the zero reference line.

2. Switch input coupling to DC. The top of the probe adjustment signal should be on the center graticule line, and the signal should reach to the next lower major division. Now you can see the difference between AC and DC coupling. The AC coupling blocks the constant part of the signal and just shows you a one half volt, peak-to-peak square wave centered on the zero reference that you set at the center of the screen. The DC coupling shows you that the constant component of the square wave is negative-going with respect to ground, because with DC coupling all signal components are connected to the vertical channel.

The Vertical Mode Controls

1. So far you've been using the scope to see what channel 1 can tell you, but that's only one of many possible vertical modes. Look at the trace for channel 2 by setting the left VERTICAL MODE switch to CH 2. Input coupling for channel 2 should still be at GND, so what you'll see is the ground reference line. Use the channel 2 POSITION control to line up this trace with the second graticule line from the top of the screen.

2. Now move the left VERTICAL MODE switch to BOTH. This lets you pick one of the vertical modes controlled by the right MODE switch. Move the right switch to ALT, the alternated mode. In ALT the trace for one channel is drawn completely before the scope switches to draw the trace for the other channel. You can see this happening when you slow down the sweep speed, so turn the SEC/DIV switch counterclockwise to 0.1 second per division. Now notice that the two dots from channel 1, which is AC-coupled, move across the screen for one sweep, then the single dot from channel 2 moves across the screen.

3. Turn the SEC/DIV switch back to 1 ms and switch to CHOP as your vertical mode. The display looks a lot like the alternated mode, but it is achieved in an entirely different way. In ALT you saw that one channel's signal was completely written before the other one was started. But when you're looking at slow signals, having only one trace at a time on screen can be a bother. In CHOP the scope switches back and forth very quickly between the two traces so that a part of one signal is drawn, then a part of the other, then the process repeats. When you look at the screen, both signals seem continuous because the scope is chopping back and forth at a very fast rate—approximately 500 kHz in the 2200-Series scopes. The CHOP mode is most useful for slow sweep speeds, and ALT is best for faster sweeps.

4. Turn the SEC/DIV switch back to 0.5 ms. There's one more vertical mode—ADD. In this mode, the two signals are either algebraically combined (channel 1 + channel 2) or differentially combined when channel 2 is inverted (channel 1 − channel 2). To see this mode in operation, set the VERTICAL MODE switches to CH 2-NORM-ADD. Connect a probe to the CH 2 BNC connector and get a display for channel 2 just like you did for channel 1. Then set the left MODE switch to BOTH. Now you can see the combined signal roughly halfway between where the two separate signals were.

THE HORIZONTAL SYSTEM

To draw a graph, your scope needs both horizontal and vertical data. The horizontal system supplies the second dimension by providing deflection voltages that move the electron beam horizontally. It also contains a sweep generator that produces a sawtooth waveform, or ramp (see Figure 7). The ramp is used to control the scope's sweep rates.

The sweep generator makes possible the unique functions found in today's modern oscilloscope. The circuit that produces a linear rate of rise in the ramp—a refinement pioneered by Tektronix—was one of the most important advances in oscillography. It meant that horizontal beam movement could be calibrated directly in units of time, and this gives you the ability to measure time between events much more accurately.

Because the sweep generator is calibrated in time, it is usually called the *time base*. The time base lets you observe the signal for the unit of time you select—either for very short times, measured in nanoseconds or microseconds—or for relatively long times of several seconds.

The horizontal system controls on the Tektronix 2225 Oscilloscope are shown in the foldout illustration at the back of this primer; the COARSE and FINE POSITION controls are near the top of the panel, and the MODE control is below

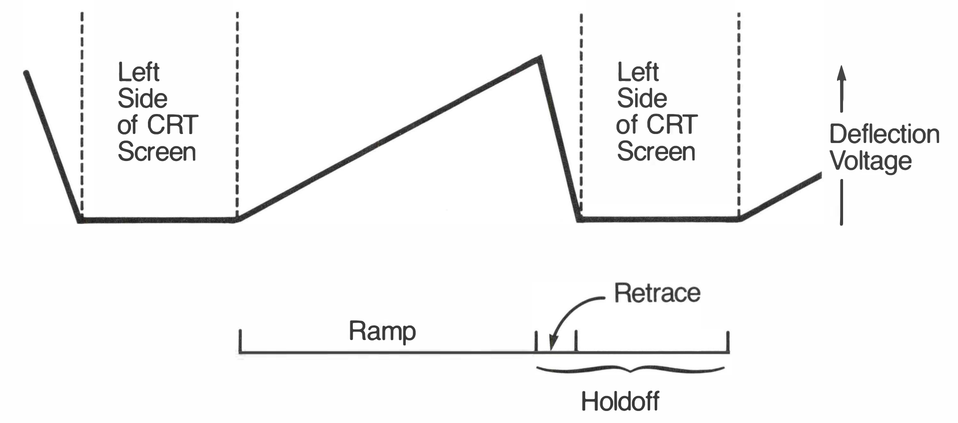


Figure 7. THE SAWTOOTH WAVEFORM is a voltage ramp produced by the sweep generator. The rising portion of the waveform is called the *ramp*, the falling edge is called the *retrace*, and the time between ramps is called the *holdoff*. The sweep of the electron beam across the screen is controlled by the ramp, and the return of the beam to the left side of the screen takes place during the retrace. During the holdoff time, the electron beam remains on the left side of the screen before starting the sweep.

them. Variable sweep-speed control is afforded by the CAL knob in the center of the SEC/DIV switch. At the bottom of this column of controls is the magnification (MAG) control.

Horizontal Operating Modes

The 2225 is capable of highly accurate timing measurements and a wide range of time-delay measurements, even though it is a single-time-base scope. Single-time-base scopes usually have only one operating mode, but the 2225 offers three. Through the interaction of the MODE and MAG switches, you not only can display the unmagnified trace (1X) alone, but also can display the same trace magnified 5, 10, or 50 times—either alone (MODE set to MAG) or together with the unmagnified trace (MODE set to ALT with the MAG switch set to either X5, X10, or X50).

Oscilloscopes such as the Tektronix 2235 have two time bases, which, in addition to waveform expansion, allow the user to make very accurate (1%) differential timing measurements. These are accomplished by setting the two time bases to different SEC/DIV values and using a calibrated delay dial.

The 2225 offers the best mix of measurement capabilities between single-time-base scopes and dual-time-base scopes. Its X1 MODE provides the same display as a basic single-time-base scope and as the A sweep on a dual-time-base scope. With the 2225 HORIZONTAL MODE set to ALT (alternate), the display alternates between the unmagnified trace (X1) and the magnified trace (X5, X10, or X50). This is the same as a dual-time-base scope operating in an alternate mode and displaying both the A time base sweep and the B time-base sweep. When the 2225 is set to MAG MODE, only the magnified trace is displayed. This is the same as a dual-time-base scope that is set to display only the B sweep.

The advantage of the 2225 is that it has most of the capabilities of a dual-time-base scope, yet it offers the operational simplicity of a single-time-base scope.

Sweep Speeds

The SEC/DIV switch lets you select the rate at which the beam sweeps across the screen; changing SEC/DIV switch settings lets you look at longer or shorter time intervals of the input signal. Like the vertical system VOLTS/DIV switch, the control markings refer to the horizontal scale factors applied to the on-screen trace. If the SEC/DIV setting is 1 ms, each horizontal major division represents 1 ms, and the total screen will be 10 ms wide.

All the instruments in the Tektronix 2200-Series offer sweep speeds from one-half second to 0.05 μs per division. Markings that appear on the SEC/DIV switch are:

.5 s	0.5 second
.2 s	0.2 second
.1 s	0.1 second
50 ms	50 milliseconds (0.05 second)
20 ms	20 milliseconds (0.02 second)
10 ms	10 milliseconds (0.01 second)
5 ms	5 milliseconds (0.005 second)
2 ms	2 milliseconds (0.002 second)
1 ms	1 millisecond (0.001 second)
.5 ms	0.5 millisecond (0.0005 second)
.2 ms	0.2 millisecond (0.0002 second)
.1 ms	0.1 millisecond (0.0001 second)
50 μs	50 microseconds (0.00005 second)
20 μs	20 microseconds (0.00002 second)
10 μs	10 microseconds (0.00001 second)
5 μs	5 microseconds (0.000005 second)
2 μs	2 microseconds (0.000002 second)
1 μs	1 microsecond (0.000001 second)
.5 μs	0.5 microsecond (0.0000005 second)
.2 μs	0.2 microsecond (0.0000002 second)
.1 μs	0.1 microsecond (0.0000001 second)
.05 μs	0.05 microsecond (0.00000005 second)

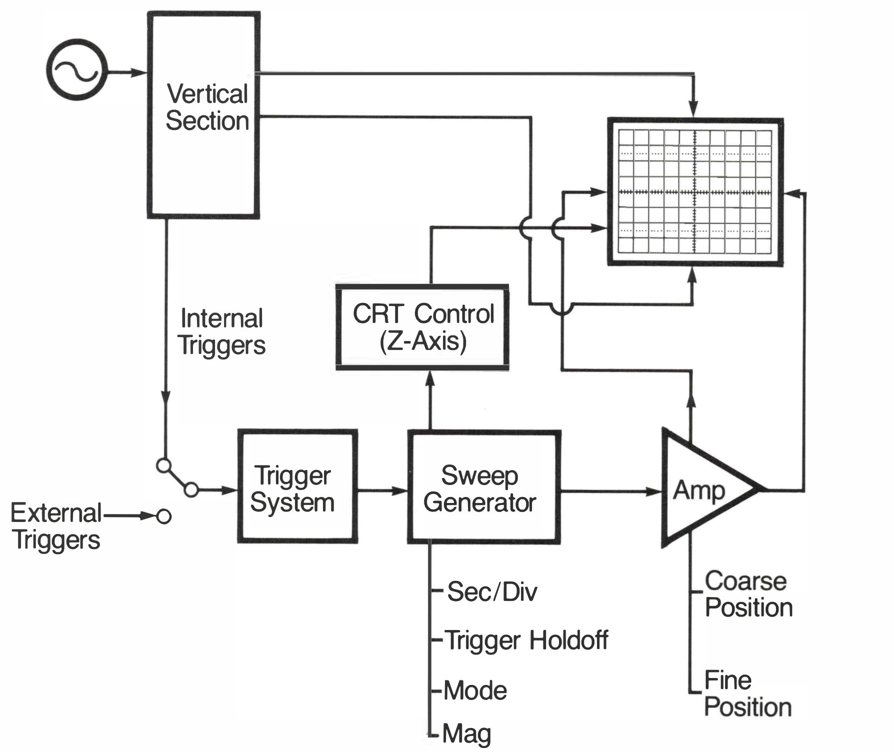


Figure 8. HORIZONTAL SYSTEM components include the sweep generator and the horizontal amplifier. The sweep generator produces a sawtooth waveform that is processed by the amplifier and applied to the horizontal deflection plates of the crt. The horizontal system also provides the scope's Z-axis, which determines whether the electron beam (intensity) is turned on or turned off (*blanked*).

Scopes also have an X-Y setting often placed on the SEC/DIV switch, for making the X-Y measurements described on page 32.

Variable SEC/DIV

Besides the calibrated speeds, you can change any sweep speed by turning the CAL control (in the center of the SEC/DIV switch) counterclockwise. This control slows the sweep speed by at least 2.5:1, making the slowest sweep 1.25 seconds per division (0.5 seconds x 2.5). Remember that the calibrated position is completely clockwise (in detent).

Horizontal Magnification and Alternate Magnification

When you select either ALT or MAG, you are multiplying the currently set sweep speed by the chosen magnification factor. For example, if the SEC/DIV switch setting is 0.05 μs and the MAG switch setting is X5, then the magnified sweep speed is a fast 10 ns per division; and when MAG is X10, the magnified sweep is a very fast 5 ns per division. Magnification is useful when you want to look at signals and see details that occur very closely together. It is especially helpful for measuring digital signal timing.

Expanding a waveform for measurement using the alternate magnification feature is accomplished with the HORIZONTAL MODE switch (set to ALT) and the POSITION control. First, locate a point of interest on the unmagnified (X1) trace.

Then, simply position that point horizontally to the center vertical graticule line. The magnified trace will be positioned to display the selected point at or about the center vertical graticule line, which is called the magnifier registration point. Use the TRACE SEP control to position the magnified trace either above or below the unmagnified trace. It's as simple as that.

Horizontal Position

You use the HORIZONTAL POSITION controls just as you use the VERTICAL POSITION controls—to change the location of waveforms on the screen. The 2225 has two HORIZONTAL POSITION controls—COARSE and FINE. The FINE control is well suited for adjusting the magnified sweep. As previously explained, the HORIZONTAL POSITION controls are also used in conjunction with the alternate magnification feature.

Using the Horizontal Controls

As you can see in Figure 8, the horizontal system can be divided into two functional blocks, the horizontal amplifier and the sweep generator.

To familiarize yourself with the horizontal system controls, follow the directions in Exercise 4 and refer to the foldout at the back of this primer for control locations. First, make sure the front-panel controls have these settings:

VERTICAL MODE: CH 1 – NORM

CH 1 VOLTS/DIV: 0.5 V (10X PROBE)

HORIZONTAL MODE: X1

SEC/DIV: 0.5 ms

TRIGGER MODE: P-P AUTO

TRIGGER SOURCE: CH 1

Exercise 4. HORIZONTAL SYSTEM CONTROLS

1. *Be sure your probe is connected to the CH 1 input BNC and its tip is attached to the PROBE ADJUST terminal. Turn on your scope, set the channel 1 input coupling switch to GND, and align the trace along the center horizontal graticule line using the channel 1 POSITION control. Then switch to AC input coupling.*

2. *Now you can use the horizontal system of your scope to look at the probe-adjustment signal. Move the waveform with the HORIZONTAL COARSE POSITION control until one rising edge is lined up with the center vertical graticule line. Examine the screen to see where the leading edge of the next pulse crosses the horizontal centerline of the graticule. Count the major and minor graticule markings along the center horizontal graticule between the successive pulse leading edges. Note the number.*

3. *Change sweep speed to 0.2 ms and line up a rising edge with the vertical graticule line on the left edge of the screen. Again count divisions to the next rising edge. Because the switch was changed from 0.5 ms to 0.2 ms, the waveform will look two and one-half times as long as before. The signal hasn't changed, of course, only the scale factor.*

4. *You'll find the variable control in the middle of the SEC/DIV switch. It's labeled CAL. The SEC/DIV switch settings are calibrated when the CAL control is fully counterclockwise in its detent. Move this control from its detent and rotate it fully counterclockwise to see the effect on sweep speed. Notice that now the cycles of the waveform are at least two and one-half times smaller. Return the CAL control to its detent.*

5. *Turn the SEC/DIV switch back to 0.5 ms, set the HORIZONTAL MODE switch to ALT, and set the MAG switch to X10. Notice that a second trace appears on the screen. This second trace is a 10X magnification of the original trace; that is, its sweep speed is ten times faster. For example, the sweep speed of the magnified trace now is 0.05 ms per division, while the sweep speed of the original (unmagnified) trace remains 0.5 ms.*

6. *The separation between the magnified and unmagnified traces can be adjusted with the TRACE SEP control. Use this control to set a convenient spacing between the two traces. Notice that only the magnified trace moves. You may have to use the VERTICAL POSITION control to center the display again.*

7. *While your scope is magnifying the probe adjustment signal, use the HORIZONTAL COARSE POSITION control. Its range is now magnified as well, and the combination of the magnified signal and COARSE POSITION control rotation lets you examine small parts of a waveform in great detail. At this point, try using the FINE POSITION control with the X5 and X50 magnification levels. Notice the effects.*

8. *Now switch HORIZONTAL MODE to MAG and notice that only the magnified trace remains on the display. Switch between X5, X10, and X50 magnification levels and notice the effect.*

9. *Return your scope to its normal sweep speed range and display by setting the MODE switch to X1.*

THE TRIGGER SYSTEM

So far you've found that the display system draws the waveforms on the screen, the vertical system supplies the vertical information for the graph, and the horizontal system provides the time axis. In other words, you know how the oscilloscope draws a graph. The only thing missing is the "when." How does the scope "know" when to start drawing the signal?

The trigger is the "when." It determines the instant that the scope starts drawing the signal. Triggering is important because acquiring time-related information is one of the primary reasons for using a scope. Equally important is that the graph of each signal should start predictably at the same point of the waveform so that the display remains stable.

The graph you see on the screen isn't a static one even though it appears to be. It's always changing— being updated with the input signal. If you're using the 0.05 μs SEC/DIV setting, the scope is drawing one graph every 0.5 μs (0.05 μs per division times 10 screen divisions). That's 2,000,000 graphs every minute (not counting retrace and holdoff times, which we'll get to shortly). Imagine the jumble on the screen if each sweep started at a different place on the signal.

But each sweep does start at the right time—if you make the right trigger system control settings. Here's how it's done. You use the TRIGGER SOURCE switches to tell the trigger circuit which trigger signal to select—channel 1, channel 2, line voltage, or an external signal. To use an external trigger signal, you connect it to the trigger system circuit using the external input (EXT INPUT) connector. You use the COUPLING switch to determine how the selected signal is to be coupled to the trigger circuits. Next you set the SLOPE and LEVEL controls to tell the trigger circuit to recognize a particular voltage level on the trigger signal. Then every time that level occurs, the sweep generator is turned on. See Figure 9 for a diagram of the process.

Instruments like those in the Tektronix 2200-Series offer a variety of trigger controls. Besides those already mentioned, you also have controls that determine how the trigger system operates (*trigger operating mode*) and how long the scope waits between triggers (*holdoff*).

Trigger control locations are illustrated in the foldout at the end of this primer. All are on the far right of the front panel. The SLOPE and LEVEL controls are grouped at the top; below them is the trigger MODE switch and below that is the HOLDOFF control. A set of three switches control the trigger SOURCE and trigger COUPLING. At the bottom is the external trigger input (EXT INPUT) connector.

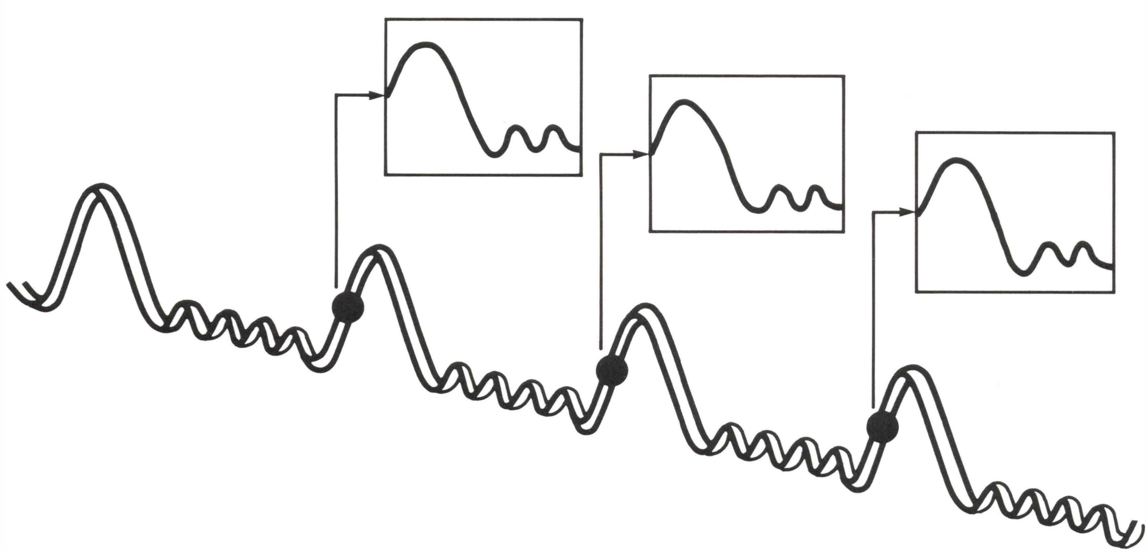


Figure 9. TRIGGERING GIVES YOU A STABLE DISPLAY because the same trigger point starts the sweep each time. The SLOPE and LEVEL controls define the trigger points on the trigger signal. When you look at a waveform on the screen, you're seeing all those sweeps overlaid in what appears to be a single picture.

Trigger Level and Slope

Controls for these functions define the trigger point. The SLOPE control determines whether the trigger point is found on the rising or the falling edge of a signal. The LEVEL control determines where on that edge the trigger point occurs (see Figure 10).

Variable Trigger Holdoff

Not every trigger event can be accepted as a trigger. The trigger system recognizes only one trigger during the sweep interval. Also, it does not recognize a trigger during retrace and for a short time afterward (the holdoff period). The retrace, as you remember from the last chapter, is the time the electron beam takes to return to the left side of the screen to start another sweep. The holdoff period provides additional time beyond the retrace and is used to ensure that your display is stable, as illustrated in Figure 11.

Sometimes the normal holdoff period isn't long enough to ensure that you get a stable display; this possibility exists when the trigger signal is a complex waveform with many possible trigger points on it. Though the waveform is repetitive, a simple trigger might get you a series of patterns on the screen instead of the same pattern each time. Digital pulse trains are a good example; each pulse is very much like any other, so there are many possible trigger points, not all of which result in the same display.

You need a way to control when the scope accepts a trigger point. The variable TRIGGER HOLDOFF control provides this capability. Because it adjusts the holdoff time of the sweep generator, this control is part of the horizontal system; but its function interacts with the trigger controls. Figure 12 depicts a situation in which the variable holdoff function is useful for extending the holdoff time.

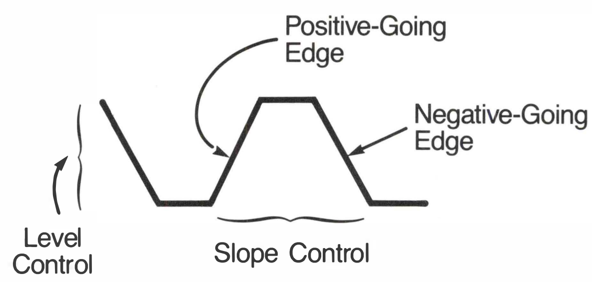


Figure 10. SLOPE AND LEVEL CONTROLS determine where on the trigger signal the trigger actually occurs. The slope control specifies either a positive (also called the *rising* or *positive going*) edge or a negative (*falling* or *negative-going*) edge. The level control lets you choose where on the selected edge the trigger event will occur.

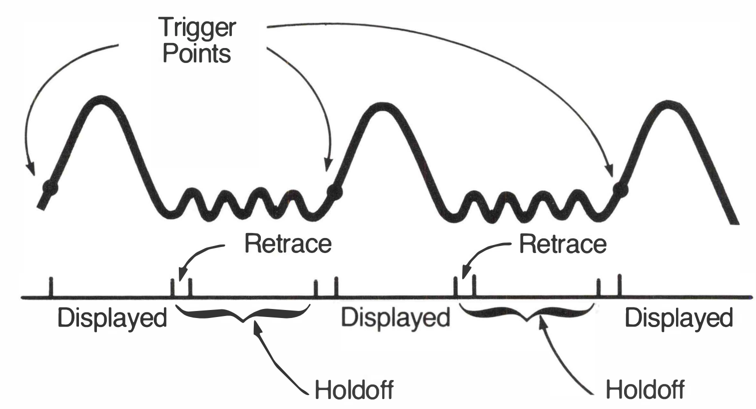


Figure 11. TRIGGER HOLDOFF TIME ensures valid triggering. In the drawing, only the labeled points start the display because no other trigger can be recognized after the sweep starts or during the retrace and holdoff periods. The retrace and holdoff times are necessary because the electron beam must be returned to the left side of the screen when the sweep ends, and because the sweep generator needs the reset time. The crt Z-axis is *blanked* (or turned off) between sweeps and *unblanked* during sweeps.

Trigger Sources

Trigger sources are grouped into two categories that depend on whether the trigger signal is provided internally or externally. The source makes no difference in how the trigger circuit operates, but the internal triggering usually uses the signal that is being displayed. That has the advantage of letting you see where you're triggering.

The two TRIGGER SOURCE switches on the front panel determine the source signal for the trigger. Internal triggering sources are enabled when you move the left SOURCE switch to the appropriate channel setting (CH 1 or CH 2), which allows you to trigger the scope on the signal coming from the selected channel. When triggering on one channel, you set the scope to trigger the sweep on some part of the waveform present on that channel.

You can also set the TRIGGER COUPLING switch to VERT MODE. When this position is selected, the scope's VERTICAL MODE switches determine what signal is used for triggering. If the VERTICAL MODE switch is set to CH 1, then the signal on channel 1 triggers the scope. If the switch is set to CH 2, then the channel 2 signal triggers the scope.

If the switch is set to BOTH-ALT, then both signals alternately trigger the scope. This is accomplished by alternating the channel 1 and channel 2 trigger signals synchronously with the display. In the BOTH-ADD mode, the algebraic sum of channel 1 and channel 2 is the triggering signal. And in the BOTH-CHOP mode, the scope triggers as it does in ADD mode, which prevents the instrument from triggering on the chop frequency instead of on your signals.

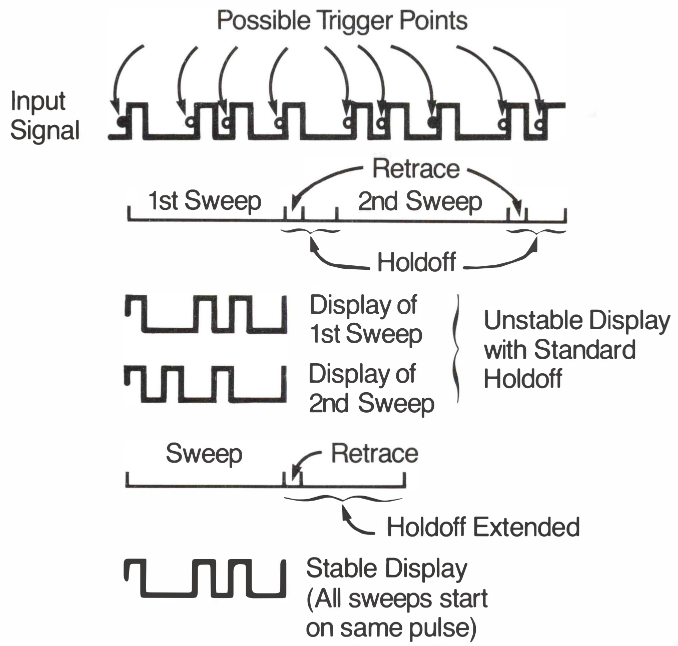


Figure 12. THE VARIABLE HOLDOFF CONTROL causes the scope to ignore some potential triggering points. In the example, all the possible trigger points on the input signal would result in an unstable display if they were accepted as sweep triggers. Changing the holdoff time to establish a trigger point that appears on the same pulse in each repetition of the input signal is the only way to ensure a stable waveform.

As you can see, VERT MODE triggering is a kind of automatic source selection that you can use when switching back and forth between vertical modes to look at different signals. This mode makes possible alternate triggering, with the scope triggering first on one channel then on the other channel. That means you can look at two completely unrelated signals at the same time. Most scopes can only trigger on either one channel or the other when the two input signals are not synchronous.

But triggering on the displayed signal isn't always what you need, so external triggering is also provided. This can give you more control over the display. To use an external trigger, set the left SOURCE switch to EXT and the right SOURCE switch to either EXT/10 or EXT. Connect the external triggering signal to the EXT INPUT connector on the front panel. External triggering often is useful in digital design and repair—when you might want to look at a long train of very similar pulses while triggering with an external clock or with a signal from another part of the circuit.

The LINE position on the source switch gives you another triggering possibility—the power line. Line triggering is useful any time you're looking at circuits dependent on the power-line frequency. Examples include devices like lighting equipment and power supplies.

The following table describes all the trigger sources possible on the Tektronix 2225 Oscilloscope.

2225 TRIGGERING SIGNALS WITH ANY TRIGGER MODE

<table>
<tr><th colspan="3">Switch Settings</th><th rowspan="3">Triggering Signal</th></tr>
<tr><th colspan="2">TRIGGER SOURCE</th><th rowspan="2">VERTICAL MODE</th></tr>
<tr><th>Left</th><th>Right</th></tr>
<tr><td>CH1</td><td rowspan="5">Disabled</td><td>CH1</td><td>Channel 1 input.</td></tr>
<tr><td rowspan="3">VERT MODE</td><td>BOTH-ALT</td><td>Alternatives between Channel 1 and Channel 2 inputs. Each input signal triggers its own display.</td></tr>
<tr><td>BOTH-CHOP</td><td rowspan="2">Algebraic sum of Channel 1 and Channel 2 inputs.</td></tr>
<tr><td>BOTH-ADD</td></tr>
<tr><td>CH 2</td><td>CH 2</td><td>Channel 2 input.</td></tr>
<tr><td rowspan="3">EXT</td><td>LINE</td><td rowspan="3">Any</td><td>Power line.</td></tr>
<tr><td>EXT/10</td><td>Signal applied to EXT INPUT connector and attenuated by a factor of 10.</td></tr>
<tr><td>EXT</td><td>Signal applied to EXT INPUT connector.</td></tr>
</table>

Trigger Operating Modes

The 2225 Oscilloscope can operate in four trigger modes: normal, peak-to-peak automatic (includes television line), television field, and single sweep.

In the peak-to-peak automatic mode (P-P AUTO), a timer starts after a triggered sweep starts. If another trigger is not generated before the timer runs out, a second trigger is generated anyway, causing the bright baseline trace to appear—even when there is no signal applied to the channel input. Timer circuits are designed to run out if the trigger-signal frequency is less than 20 Hz. In the 2200-Series scopes, the peak-to-peak automatic mode is a peak-detecting mode. For most of the signals you'll be measuring, the peak-to-peak automatic mode matches the TRIGGER LEVEL control range to the trigger signal peak-to-peak amplitude. Because of this automatic action, you will probably never set the TRIGGER LEVEL control outside the signal range. No matter where the LEVEL control is set, a triggered sweep will occur. The P-P AUTO mode lets you trigger on signals having a changing amplitude pattern or waveshape—and it lets you do this without adjusting the LEVEL control.

The normal trigger mode (labeled NORM on the TRIGGER MODE switch) is one of the most useful, because it can handle a wider range of triggering signals than any other mode—from dc to 50 MHz. It's used primarily for very low frequency signals (less than 100 Hz). When there's no trigger, the normal mode does not permit a trace to be drawn on the screen.

Another useful operating mode is television triggering. Most scopes with this mode let you trigger on TV fields at sweep speeds of 0.1 ms per division and slower and on TV lines at 50 μs per division or faster. With a 2200-Series scope, you can trigger on either TV fields or TV lines at any sweep speed. For field triggering, set the TRIGGER MODE switch to TV FIELD and for line triggering, set it to P-P AUTO setting/TV LINE.

You'll probably use the normal and peak-to-peak automatic modes most often—NORM because it's the most versatile and P-P AUTO because it's essentially automatic. But you should be aware of a couple limitations in the P-P AUTO mode. It's possible to have a low-frequency signal with a repetition rate that is mismatched to the run-out of the automatic mode timer, thus causing the signal to be unsteady. Also, the P-P AUTO mode cannot trigger on very low frequency trigger signals. However, for these cases, use the NORM mode, which gives you a stable trigger at any frequency.

Single-sweep mode (labeled SGL SWP) operates exactly as its name implies—it triggers a sweep only one time. After selecting SGL SWP TRIGGER MODE, the trigger system must be readied, or armed, to accept the very next trigger event that occurs. This is done by momentarily pressing then releasing the RESET button, which also causes the READY-TRIG'D indicator to illuminate. With the trigger circuit armed, the

crt screen is blank. When the trigger event or signal occurs, the sweep is started. And when one sweep is completely across the crt, the trigger system is halted. This stops any more sweeps from occurring and extinguishes the READY TRIG'D indicator.

The SGL SWP mode typically is used for waveform photography and for babysitting while looking for glitches. To perform the latter, set up the scope for displaying a single sweep, being careful that the SLOPE and LEVEL controls are both complementary to the event you are seeking. Then, if the scope user leaves the test area and later returns to see the READY-TRIG'D indicator extinguished, the operator knows that the event occurred. An oscilloscope camera could be used to capture this event on a permanent film record. This is achieved by leaving the shutter open, using the B (BULB) setting.

Trigger Coupling

Just as you may select either alternating or direct coupling when connecting an input signal to the scope's vertical system, the 2225 Oscilloscope lets you choose the kind of coupling needed to connect either an internal or an external trigger signal to the trigger-system circuits.

Besides AC and DC coupling, the trigger system on the 2225 also has high-frequency rejection (HF REJ) and low-frequency rejection (LF REJ), which are useful for eliminating specific frequency components from the trigger signal. As its label implies, HF REJ removes the high-frequency portion of the triggering signal, allowing only the low-frequency components to pass on to the triggering system and subsequently start the sweep. Selecting LF REJ accomplishes just the opposite effect. These two frequency rejection features are useful for eliminating noise that may be riding on top of input signals. This noise may be preventing the trigger signal from starting the sweep at the same point every time. Typically, the HF and LF rejection filters roll off at 30 kHz, as illustrated in Figure 13.

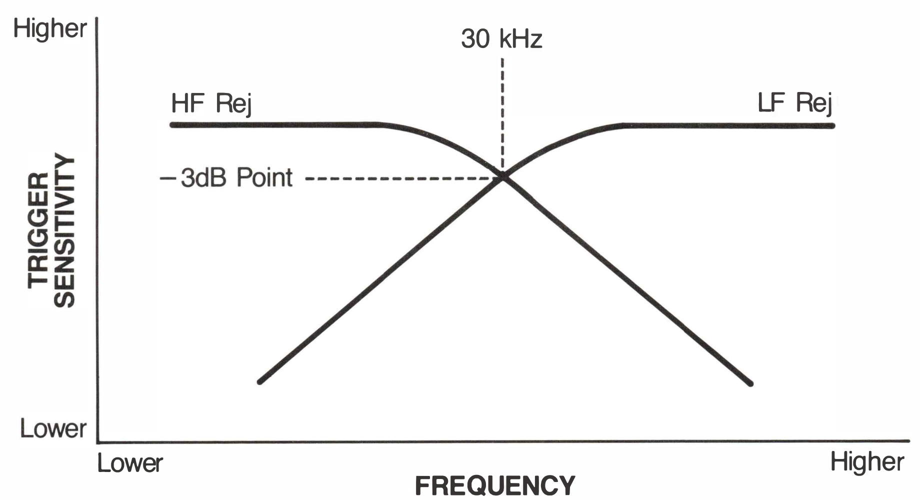


Figure 13. TRIGGERING STABILITY can be improved with HF REJ and LF REJ COUPLING. The high- and low-frequency rejection filters roll off at 30 kHz.

Here's a review of the 2200-Series trigger modes:

TRIGGER OPERATING MODE	TRIGGER MODE SETTING
Automatic Peak-to-Peak and Television Line	P-P AUTO
Normal	NORM
Television Field	TV FIELD
Single Sweep	SGL SWP

Remember that for CH 1, CH 2, and VERT MODE TRIGGER SOURCE, the triggering signal first goes through the VERTICAL input coupling circuit. Thus, if AC input coupling is selected, only the AC component of the input signal gets to the trigger system—even if TRIGGER COUPLING is set to DC. The 2225's greater trigger versatility is outlined by the following table.

Using the Trigger Controls

To review what you've learned about the trigger circuit and its controls (shown schematically in Figure 14), first set your controls as follows.

VERTICAL MODE: CH 1

CH 1 VOLTS/DIV: 0.2 (10X PROBE)

- Variable (CAL): In detent and pushed in
- Coupling: DC

HORIZONTAL MODE: X1

SEC/DIV: 0.5 ms

SEC/DIV CAL: In detent

TRIGGER MODE: P-P AUTO

- SOURCE: CH 1
- COUPLING: DC

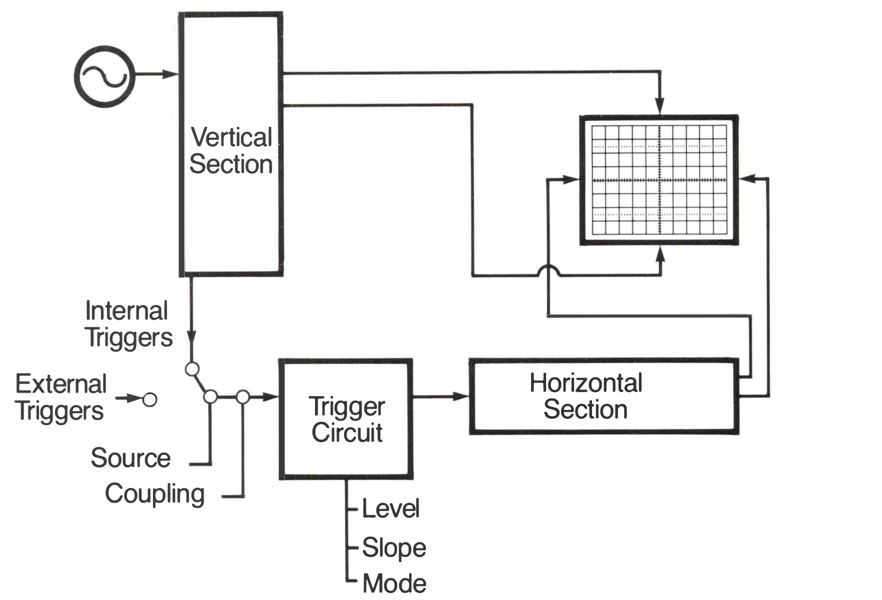


Figure 14. THE TRIGGER CIRCUIT AND ITS CONTROLS are shown here. Trigger SOURCE selects the signal that will be used for triggering the sweep. The COUPLING control affects the connection of the selected trigger signal to the trigger circuit. The LEVEL and SLOPE controls determine where the trigger point will be on the trigger signal. And the MODE control determines the operations of the trigger circuit.

Connect the probe to the CH 1 input connector and turn on your scope. Apply the probe tip to the PROBE ADJUST terminal and follow the directions in Exercise 5. Use the foldout figure to remind yourself of the correct control locations.

TRIGGER COUPLING	FUNCTION
AC	Blocks dc components of the trigger signal and couples only the ac components.
LF REJ	Filters the low frequencies from the trigger signal and passes only the high frequencies (above 30 kHz). Signal is AC coupled.
HF REJ	Filters the high frequencies from the trigger signal and passes only the low frequencies (below 30 kHz). Signal is DC coupled.
DC	Passes both ac and dc trigger-signal components to the trigger circuit.

Exercise 5. TRIGGER CONTROLS

1. Move the trace to the right with the HORIZONTAL COARSE POSITION control until you can see the beginning of the signal. You'll probably have to increase the intensity to see the faster vertical part of the waveform. Watch the signal while you operate the SLOPE control. If you select the rising edge (_|‾), the signal on the screen starts with a positive-going slope, or rising edge; the other position (‾|_) makes the scope trigger on a negative-going slope, or falling edge.

2. Now turn the LEVEL control back and forth as far as it will go; you'll see the leading edge climb up and down the signal. The scope remains triggered because you are using the P-P AUTO setting. Now set input coupling to GND and notice that a bright baseline trace is present. The baseline trace appears because of the automatic-mode timer described earlier in this chapter.

3. Change TRIGGER MODE to NORM and channel 1 input coupling to DC. Now when you use the LEVEL control to move the trigger point, you'll find places where the scope is untriggered (a blank crt screen). Retrigger on the signal, then switch input coupling to GND. Notice that in NORM mode the screen is blank (no bright baseline). This is an illustration of the essential difference between normal and automatic triggering.

4. Switch input coupling back to DC and adjust the TRIGGER LEVEL control for a stable display. Set TRIGGER MODE to SGL SWP, then return channel 1 input coupling to GND. Now momentarily push in and release the single-sweep RESET button and observe that the READY-TRIG'D indicator is illumined. At this point, rotate the INTENSITY control fully clockwise to facilitate viewing the single-sweep display. Finally, move the input coupling switch from GND to DC and observe that only one sweep occurs. Press RESET each time you want to see the single-sweep display again.

5. Without a trigger signal applied to the EXT INPUT connector, it's impossible to show you the use of this trigger source, but the TRIGGER MODE, SLOPE, and LEVEL controls all work the same for either internal or external triggers. One difference between internal and external trigger sources, however, is the sensitivity of the trigger circuit. All external sources are specified and measured in voltage (say, 150 mV) while internal sources are rated in divisions. In other words, the displayed amplitude for internal signals makes a difference.

To demonstrate this, change both the VERTICAL MODE switch and the TRIGGER SOURCE switch back to CH 1. Then set the CH 1 VOLTS/DIV switch to 0.5 V (10X PROBE) and move the TRIGGER MODE switch to NORM. Rotate the LEVEL control and notice the control range. Now change the CH 1 VOLTS/DIV switch to 0.1 V (10X PROBE) and rotate the LEVEL control. Notice that you have a broader control range now.

6. Change the SEC/DIV switch setting to 1 ms and observe the rate at which the display is updated by the recurring sweep. Now rotate the TRIGGER HOLDOFF control fully clockwise from MIN to maximum sweep-holdoff time. Notice that the display update rate is much less now. This is due to the increased holdoff time. As previously described in this chapter, variable holdoff is designed for triggering on complex waveform periods.

7. There are several other features, but they are not easily demonstrated with the PROBE ADJUST signal. You'll find them useful the first time your own measurement applications require them—applications such as video service, where the TV FIELD and TV LINE triggering modes would be needed. Also, using VERT MODE TRIGGER SOURCE when you've selected BOTH-ALT VERTICAL MODE lets you make timing measurements on two asynchronous (time unrelated) signals. Using the TRIGGER SOURCE called LINE is important for applications where the signal applied to the scope's vertical input is time related to the power source, or mains, such as a power supply. Finally, keep in mind that the use of LF REJ and HF REJ TRIGGER COUPLING is ideal in noisy signal environments.

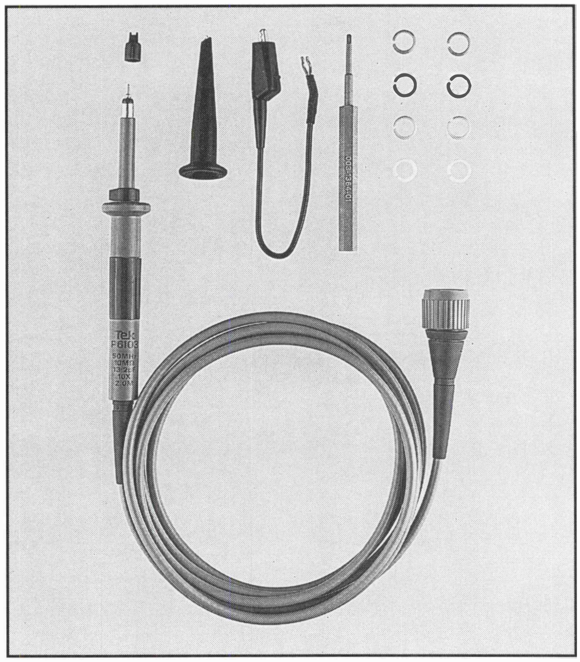


Figure 15. PROBES CONNECT THE SCOPE AND THE CIRCUIT UNDER TEST. Tektronix probes consist of a patented resistive cable and a grounded shield. Two P6103 10X passive probes and the accessories pictured above are supplied with every Tektronix 2225 scope. These modular, high-impedance, minimum-loading probes incorporate ruggedized probe tips and eliminate the bulky compensation box at the front of the scope. The accessories for each probe (from left to right) are: an IC tester tip cover, a retractable-hook tip, a ground lead, a compensation adjustment tool, and marker bands.

Connecting measurement test points to the inputs of your oscilloscope is best done with a probe like the one illustrated in Figure 15. Though you could connect the scope and the circuit under test with just a wire, this simplest of connections would not let you realize the full capabilities of your scope. The connection would probably load the circuit excessively, and the wire would act as an antenna, picking up stray signals such as 60-Hz power, line noise, radio transmissions, and TV stations. These signals would be displayed on the screen along with the signal of interest.

Circuit Loading

Using a probe instead of a bare wire minimizes stray signals, but *circuit loading* is still an undesirable side effect. Depending on how great the loading is, circuit-loading effect modifies the circuit environment and changes the signals in the circuit under test—either a little or a lot.

Circuit loading is resistive, capacitive, and inductive. For signal frequencies under 5 kHz, the most important component of loading is resistance. In these situations, you can avoid significant circuit loading by using a probe with a resistance at least two orders of magnitude greater than the circuit impedance (100 MΩ probes for 1 MΩ sources; 1 MΩ probes for (10 kΩ sources; and so on).

When you are making measurements on a circuit that contains high frequency signals, inductance and capacitance become important. You can't avoid adding capacitance when making a connection, but you can avoid adding more capacitance than necessary.

One way to do that is to use an attenuator probe. Its design greatly reduces circuit loading. Instead of loading the test circuit with capacitance from the probe tip, its cable, and the scope's input circuitry, the 10X attenuator probe introduces about ten times less capacitance—as little as 10 to 14 picofarads (abbreviated *pF* and commonly pronounced *puff*). The penalty is a reduction in test signal amplitude as seen on the screen; this is caused by the 10:1 attenuation.

The Tektronix 2225 Oscilloscope includes two P6103 10X modular construction probes that incorporate ruggedized probe tips. These probes are adjustable so you can compensate them for variations in oscilloscope input capacitance. Because the compensation adjustments are built into the probe body itself, you no longer are bothered by the bulky compensation box on the cable end that attaches to the front of the scope. *Probe compensation* is the first step in Exercise 3. Your scope has a reference signal available at the PROBE ADJUST terminal on the front panel.

Remember that when you are measuring high frequencies, the impedance (resistance and reactance) of the probe changes with frequency. The probe's specification sheet or manual will contain a chart, like the one in Figure 16, that shows this change. Also, when making high-frequency measurements, be sure to ground the probe securely with as short a ground lead as possible. In some very high frequency applications, a special probe socket is available that can be installed directly into the circuit. When the probe tip is inserted into the socket, the ground collar at the probe tip becomes the ground connection, and no separate lead is necessary. This type of connection gives you the shortest possible ground path, thereby minimizing impedance loading.

Measurement System Bandwidth

Then there is one more probe characteristic to consider—bandwidth. Like scopes, probes have bandwidth limitations; each has a specified range within which it does not attenuate the signal's amplitude more than −3 dB (0.707 of the original value). But don't assume that a 50-MHz probe and a 50-MHz scope automatically give you 50-MHz measurement capability. The rise time of the probe and scope combination will equal approximately the square root of the sum of the squares of the individual rise times (also see Chapter 10). For example, if both the probe and the scope have rise times of 7.0 ns:

$$t_{r(sys)} = \sqrt{t^2_{r(s)} + t^2_{r(p)}}$$

$$t_{r(sys)} = \sqrt{49 + 49}$$

That works out to 9.9 ns, which is equivalent to a system bandwidth of 35.36 MHz, because:

$BW(\text{in MHz}) = 350/t_r(\text{in ns})$

To get the full bandwidth from your scope, you need more bandwidth from the probe. It's important, therefore, to use the particular probe designed for that instrument. For example, in the case of the 2225 Oscilloscope and the P6103 10X Passive Probe, the probe and scope have been designed to function together, providing you a full 50-MHz bandwidth at the probe tip.

Probe Types

Probes are classified generally as either voltage-sensing or current-sensing. Voltage-sensing probes are divided further into passive and active types. Refer to the following table for selecting the probe type that will meet your measurement requirements.

Selecting a Probe

For most applications, use the probes that were supplied with your scope. Usually these are attenuator probes. Compensation should be adjusted to ensure that the probe can faithfully reproduce the signal for your scope. If you're not going to use the probes that came with your scope, select a probe based on the voltage you intend to measure. For example, if you're going to be looking at a 50-V signal and the largest vertical sensitivity is 5 V per division, that signal will take up 10 major divisions of the screen. You would need the attenuation of a 10X probe to reduce the amplitude of the signal to reasonable proportions.

Proper termination to avoid unwanted signal reflections in the cable is important. Probe and cable combinations designed to drive 1 MΩ inputs are engineered to suppress these reflections. But, for 50-Ω scopes, use 50-Ω probes. The proper termination also is necessary when you use a coaxial cable instead of a probe. If you use a 50-Ω cable and a 1-MΩ scope, be sure you also use a 50-Ω terminator at the scope input.

The probe's ruggedness and flexibility, as well as the length of its cable, can also be important. The longer the cable, the greater the capacitance at the probe tip. Remember? Check the specifications to see whether the probe bandwidth is sufficient and make sure you have the adapter and tips you'll need. Most modern probes feature interchangeable tips and adapters for many applications. Retractable hook tips let you attach the probe to most circuit components. Other adapters either connect probe leads to coaxial connectors or slip over square pins. Alligator clips for contacting large-diameter test points are another possibility.

For the reasons already mentioned (probe bandwidth, circuit loading, and termination), the best way to ensure that your scope and probe measurement system has the least distorting effect on your measurements is to use the probe recommended for your scope. And always make sure it's compensated.

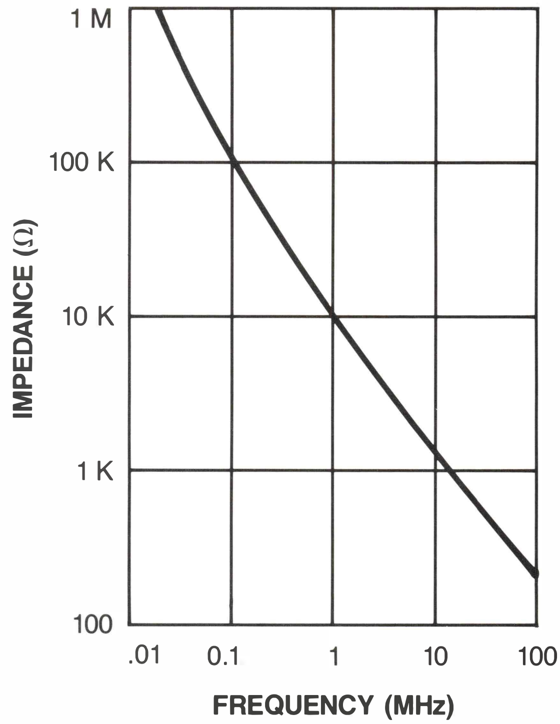


Figure 16. PROBE IMPEDANCE IS RELATED TO FREQUENCY, as shown in this graph. The curves plot both impedance (Z) in ohms and phase (θ) in degrees against frequency in megahertz. The plot shown is for the Tektronix P6103 probe with a 2-meter cable.

PROBE TYPES	CHARACTERISTICS
1X Passive, Voltage-sensing	No signal reduction, which allows maximum Voltage-sensing sensitivity at the probe tip; bandwidth typically ranges from 4 MHz to 34 MHz; high capacitance, typically 32 pF to 112 pF; signal handling to 500 V.
10X/100X/1000X Passive, Voltage-sensing, Attenuator	Attenuates signals; bandwidths to 350 MHz; adjustable capacitance; signal handling to 500 V (10X), 1.5 kV (100X), or 20 kV (1000X).
Active, Voltage-sensing, FET	Switchable attenuation; capacitance as low as 1.5 pF; more expensive, less rugged than other types; limited dynamic range; bandwidths to 900 MHz; minimum circuit loading.
Current-sensing	Measure currents from 1 mA to 1000 A; DC to 50 MHz; very low circuit loading.
High voltage	Signal handling to 40 kV.

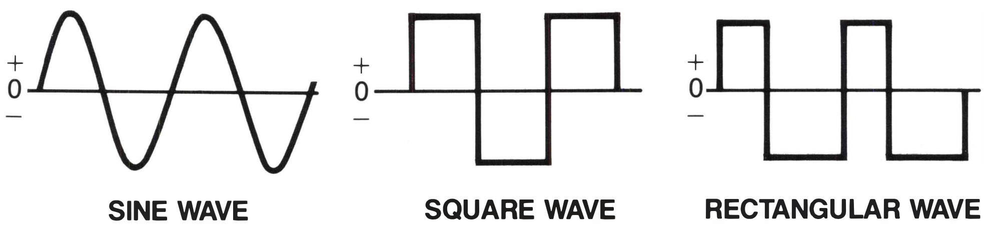
PART II. MAKING MEASUREMENTS

A *wave* is a disturbance traveling through a medium, and a *waveform* is a graphic representation of a wave. Like a wave, a waveform depends both on movement and on time. The ripple on the surface of a pond is a movement of water in time. The waveform on the oscilloscope screen is a movement of an electron beam over time.

Changes over time form the wave shape, the most readily identifiable characteristic of a waveform. Figure 17 illustrates some common wave shapes.

Waveshapes tell you a great deal about the signal. Any time you see a change in the vertical dimension of a signal, you know that this amplitude change represents a change in voltage. Anytime there's a flat horizontal line, there is no change for that length of time. Straight diagonal lines mean a linear change—rise or fall of voltage at a steady rate over time. Sharp angles on a waveform mean sudden change.

But wave shapes alone are not the whole story. To completely describe a waveform, you'll want to find its particular parameters. Depending on the signal, these parameters might be amplitude, period, frequency, width, rise time, or phase. You can review these signal parameters in Figures 18 through 23.



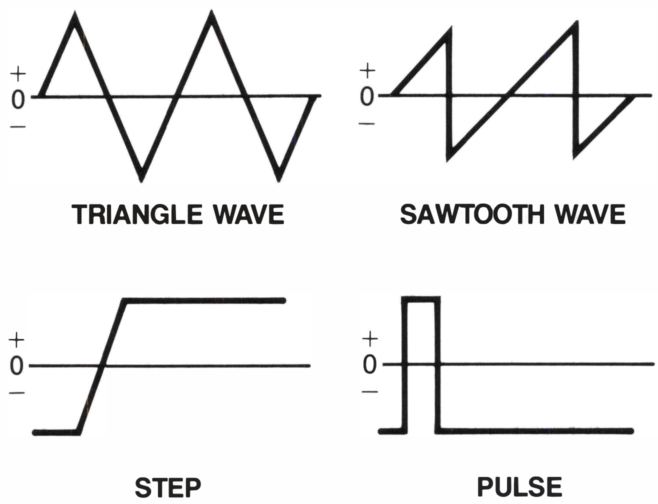


Figure 17. BASIC WAVE SHAPES include *sine* waves and various nonsinusoidal waves such as *square* waves, *rectangle* waves, *triangle* waves, and *sawtooth* waves. In a square wave, equal amounts of time are spent in each of two states (high and low). Triangle and sawtooth waves are usually the result of circuits designed to control voltage with respect to time, such as the sweep of an oscilloscope or some television circuits. In these waveforms, one or both transitions from state to state are made with a steady variation at a constant rate —a *ramp*. Changes from one state to another on all waveforms except sine waves are called transitions. The last two drawings represent aperiodic single shot waveforms. The first is a *pulse*; all pulses are marked by a rise, a time duration, and a decay. The second is a *step* —actually a single transition.

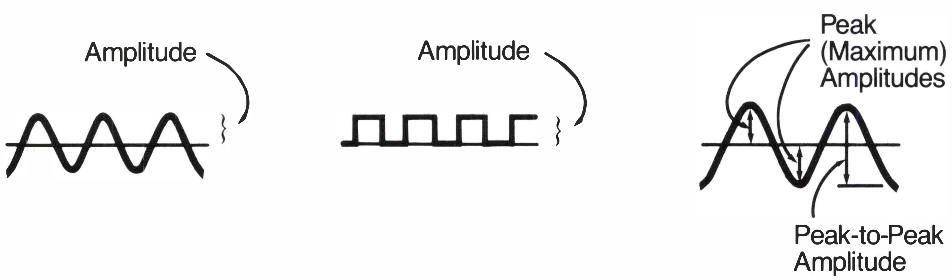


Figure 18. AMPLITUDE, A CHARACTERISTIC OF ALL WAVEFORMS, is the amount of displacement from equilibrium at a particular point in time. Note that without a modifier, the word means the maximum change from a reference without regard to the direction of the change. In the top two drawings above (sine wave and square wave), the amplitudes are equal, even though the sine wave is larger from peak to peak. In the third drawing, an alternating current waveform is shown with its peak (or maximum) amplitude and peak-to-peak amplitude parameters annotated. In oscilloscope measurements, amplitude usually means peak-to-peak amplitude.

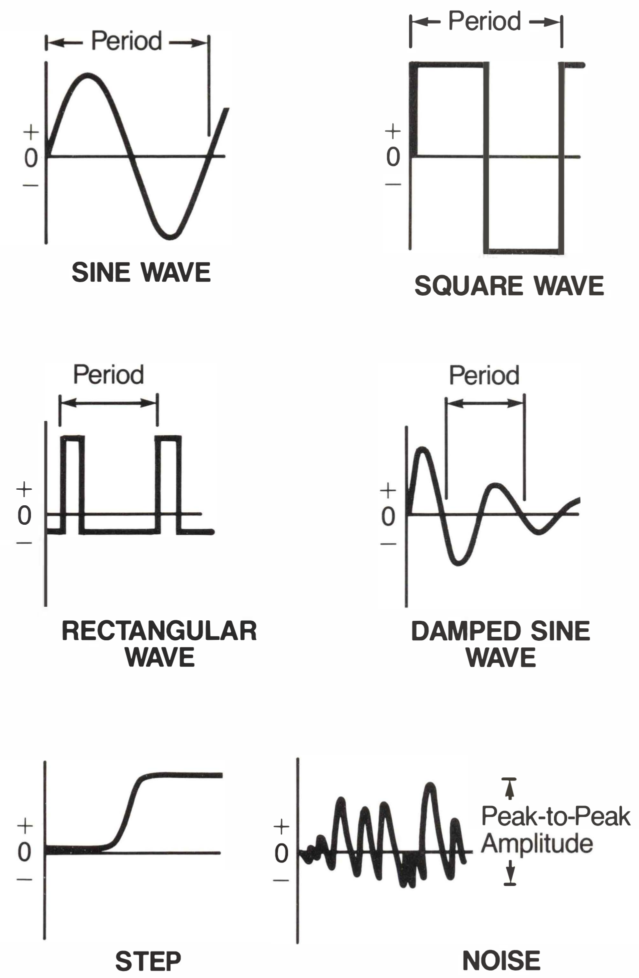


Figure 19. PERIOD IS THE TIME REQUIRED FOR ONE CYCLE OF A REPETITIVE SIGNAL and is expressed in units of time. Period (its symbol is T) is a parameter whether the signal is symmetrically shaped (like the sine and square waves) or whether the signal has a more complex and asymmetrical shape (like the rectangular wave and the damped sine wave). One-time signals such as the step and uncorrelated (having no time relation) signals such as noise have no period.

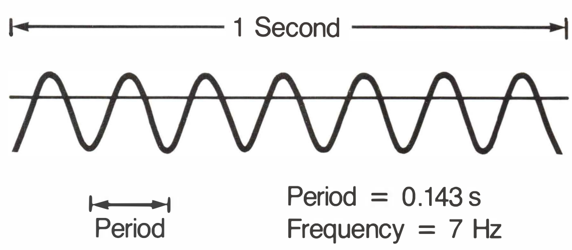


Figure 20. IF A SIGNAL IS PERIODIC IT HAS FREQUENCY. Frequency (f) is the number of times a signal repeats itself in a second and is measured in hertz: 1 Hz = 1 cycle per second, 1 kHz (kilohertz) = 1000 cycles per second, and 1 MHz (megahertz) = 1,000,000 cycles per second. Period and frequency are reciprocal: 1/period = frequency, and 1/frequency = period. For example, a 7-Hz signal has a period of 0.143 seconds, since: 1 cycle ÷ 7 Hz = 0.143 s and 1 cycle ÷ 0.143 s = 7 Hz.

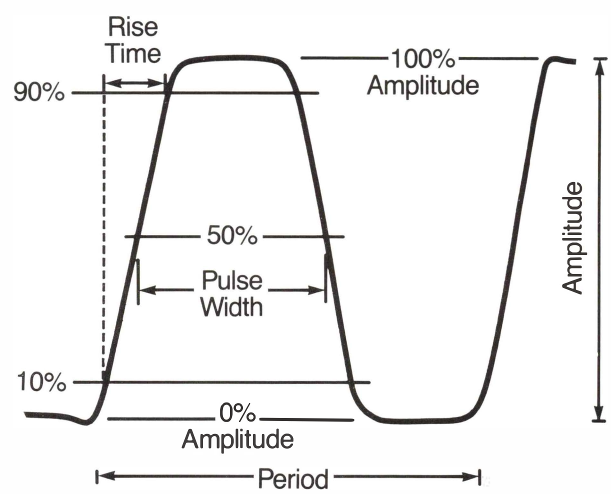


Figure 21. THE PARAMETERS OF A PULSE can be important in a number of different applications, including digital circuitry, X ray equipment, and data communications. Pulse specifications include transition times measured on the leading edge of a positive-going transition; this is the *rise time*. *Fall time* is the transition time on a negative-going trailing edge. *Pulse width* is measured at the 50% amplitude points, and *amplitude* is measured from 0% to 100%. Any displacement of the base of the pulse from zero volts is the *dc offset*.

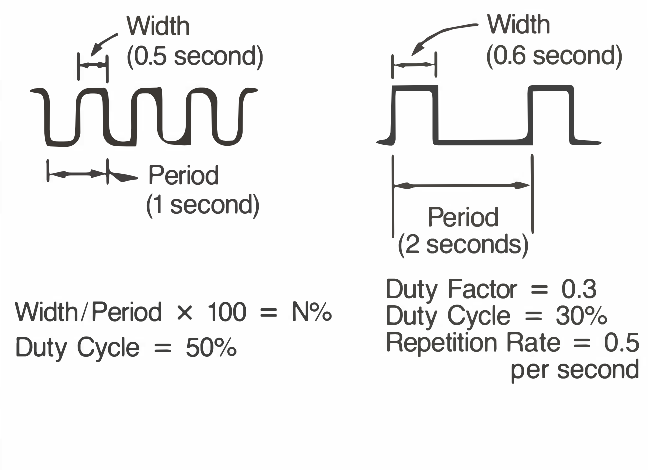


Figure 22. DUTY CYCLE, DUTY FACTOR, AND REPETITION RATE are parameters of rectangular waves. They are particularly important in digital circuitry. *Duty cycle* is the ratio of pulse width to signal period, expressed as a percentage. For square waves, it's always 50%, as you can see in the top drawing. For the rectangular waveform in the bottom drawing, it's 30%. *Duty factor* is the same thing as duty cycle, except that it is expressed as a decimal instead of a percentage. *Repetition rate* describes how often a pulse train occurs and is used instead of frequency to describe rectangular waveforms.

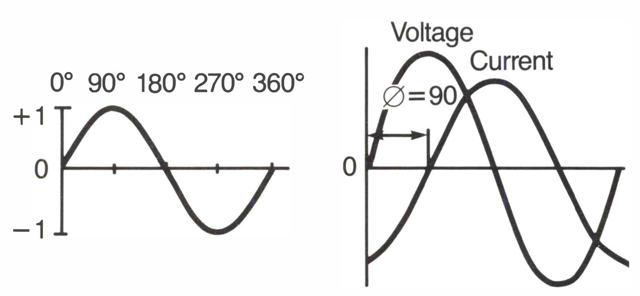


Figure 23. PHASE IS BEST EXPLAINED WITH A SINE WAVE. Remember that this waveform type is based on the sine of all angles from 0° through 360°. The result is a plot that changes from 0 at 0°, 1 at 90°, 0 again at 180°, −1 at 270°, and finally 0 again at 360°. Consequently, it is useful to refer to the *phase angle* (or simply *phase*) of a sine wave when you want to describe how much of the period has elapsed. In another usage, *phase shift* describes a relationship between two signals. Picture two clocks with their second hands sweeping the dial every 60 seconds. If the second hands reach twelve at the same time, the clocks are *in phase*; if they don't, the clocks are *out of phase*. *Phase shift* expresses the amount that two signals are out of phase. To illustrate, the waveform labeled current in the drawing is said to be 90° out of phase with the voltage waveform. Other ways of reporting the same information are: the Current waveform lags the Voltage waveform by 90°, or the Current waveform has a 90° phase angle with respect to the Voltage waveform. Note that there is always a reference to another waveform; in this case, the Current waveform relative to the Voltage waveform for an inductor.

SAFETY

Before you make any oscilloscope measurement, remember that you must be careful when you work with electrical equipment. Observe all safety precautions described in the operator's and service manuals for the equipment you're working on.

Some general rules about servicing electrical equipment are worth repeating here. Always service electrical devices with someone else present—don't service alone. Know the symbols for dangerous circuits and observe the safety instructions for the equipment you're working on. Don't operate or service an electrical device in an explosive atmosphere. Ground both your scope and the circuit under test to the same ground if possible. Remember that if you lose the scope's power-cord ground, all accessible conductive parts—including knobs that appear to be insulated—can give you a shock. To avoid personal injury, don't touch exposed connections or components in the circuit under test when the power is on. And remember to consult the service manual for the equipment you are working on.

Then there are a few rules about the scope itself. To avoid a shock, plug the power cord of the scope into a properly wired receptacle before connecting your probes. Use the appropriate power cord for your scope, and then only if it is in good condition. If the power cord is cracked or broken or has any pins missing, replace it. Use the correct fuse to avoid fire hazards. Don't remove covers and panels on your scope without the proper training.

For accurate oscilloscope measurements, make sure your system is properly set up each time you begin using your scope.

Compensating the Probe

Most measurements you make with an oscilloscope require an attenuator probe, which as you learned earlier, is any probe that reduces voltage. The most common are 10X (read: ten times) passive probes. These reduce the amplitude of the signal and the circuit loading by a factor of 10:1.

Before using an attenuator probe, make sure it's compensated. Figure 24 illustrates what can happen to the waveforms you'll see when the probe is not properly compensated.

Note that you should compensate the probe (with the accessory tip you will use) to the vertical channel you plan to use. Don't compensate it on one channel, then use it on another.

Checking the Controls

Forgetting to compensate the probe is the most common mistake in making oscilloscope measurements. Forgetting to check the front panel controls is the second most frequent. Here are some things to check on your Tektronix 2225 scope, arranged according to functional blocks.

Check vertical system controls:

- Vertical MODE switches should be set to display the signal from the proper channel(s).
- Channel 2 MODE (center switch) should be set to NORM (unless you want it to be inverted).
- The VOLTS/DIV switches should be set to the appropriate settings. Use the VOLTS/DIV readout that matches the probe, either 1X or 10X PROBE.
- Variable CAL controls for CH 1 and CH 2 should be in their detent (calibrated) positions and pressed in (for X1 vertical magnification).
- Input coupling switches should be set for the type of signal applied to the input or for the measurements that you will make.

Check the horizontal system controls to be sure that the SEC/DIV variable (CAL) control is in its calibrated detent (fully clockwise) and that the MODE switch is set to one of the following:

- X1—When you are not making measurements requiring waveform expansion.
- ALT—When waveform points of interest are to be located and viewed on both the unmagnified and the magnified traces simultaneously.
- MAG—When you want to view only the magnified trace.

Check the trigger system controls to make sure that your scope will select the proper SLOPE on the trigger signal, that the correct operating MODE will be used, and that the appropriate SOURCE and COUPLING are selected. Also make sure that the trigger variable HOLDOFF control is set to minimum (MIN).

Handling a Probe

Before you probe a circuit, make sure you have the correct probe tips and adapters for the circuits you will be working on. Tips available for the Tektronix P6103 10X probes were illustrated in Figure 15.

Then make sure that the ground in the circuit under test is the same as the scope ground—don't just assume that it is. The scope ground will always be earth ground as long as you're using the proper power cord and plug. Check the circuit ground by first attaching the ground lead of your probe to a known earth ground. Then touch the probe tip to the point you think is ground. Do this before you make a *hard* ground—that is, attaching the ground strap of your probe.

If you're going to be probing a lot of different points in the same circuit and measuring frequencies less than 5 MHz, you can ground that circuit to your scope once instead of each time you move the probe. To do this, just connect the circuit ground to the jack marked on the front panel.

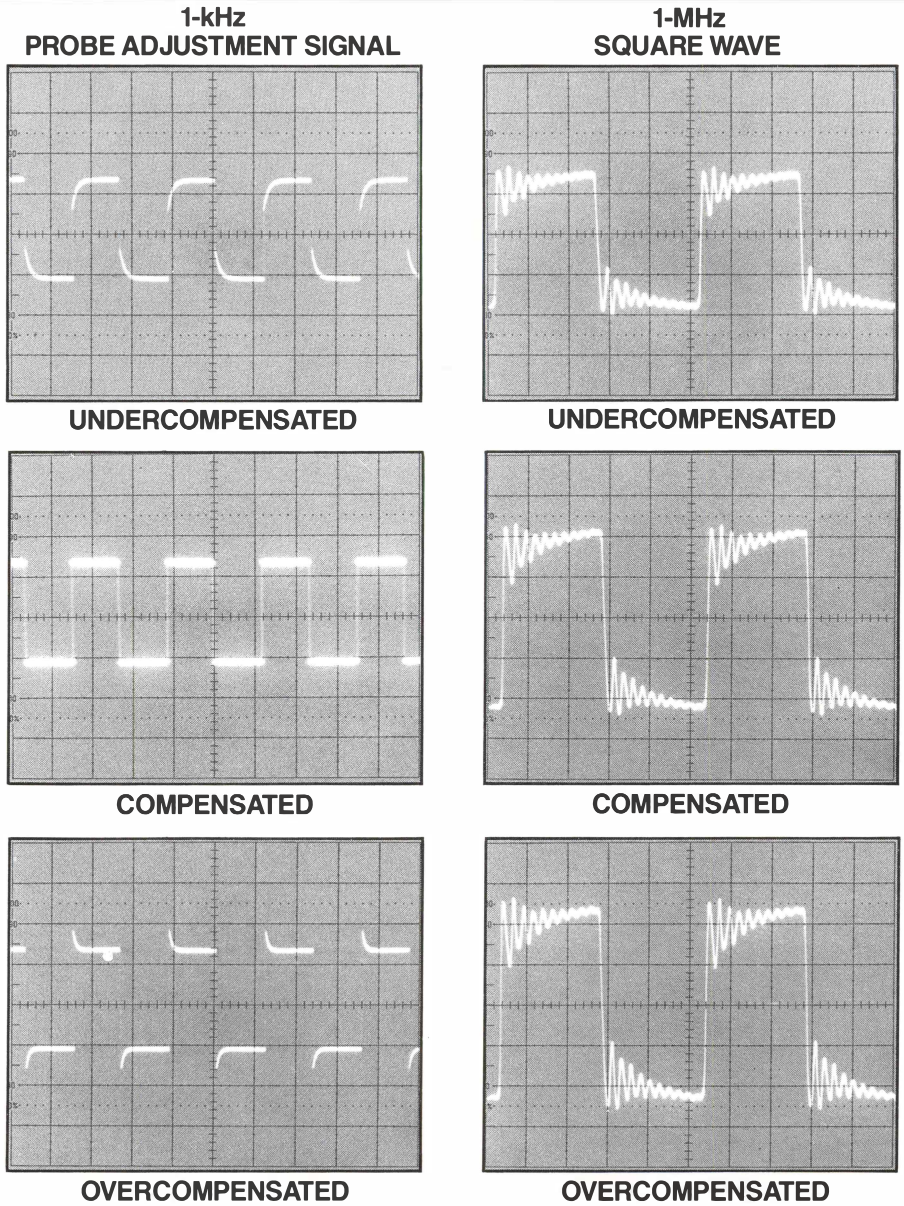


Figure 24. IMPROPERLY COMPENSATED PROBES can distort the waveforms you see on the screen of your scope. In the photographs, the 1-kHz probe-adjustment signal and a 1-MHz square wave are shown as they would appear with proper and improper compensations. Notice the changes in amplitude and ringing on the 1-MHz square wave with differences in compensation.

Rather than showing how to make every possible measurement, this chapter describes common measurement techniques you can use in many applications.

The Foundations: Amplitude and Time Measurements

The two most basic measurements you can make are amplitude and time. Almost every other measurement is based on one of these two fundamental techniques.

Since the oscilloscope is a voltage-measuring device, voltage is shown as amplitude on your scope screen. Of course, voltage, current, resistance, and power (watts) are related in the following way:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \qquad \text{Current} = \frac{\text{Power}}{\text{Voltage}}$$

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \qquad \text{Voltage} = \frac{\text{Power}}{\text{Current}}$$

$$\text{Voltage} = \text{Current} \times \text{Resistance} \qquad \text{Power} = \text{Current} \times \text{Voltage}$$

Amplitude measurements are best made with a signal that covers most of the screen vertically. This is done because the more screen area you use, the better measurement resolution you can achieve. Use Exercise 6 for practicing amplitude measurements.

Time measurements are also more accurate when the signal covers a large area of the screen. Continue with the setup you had for the amplitude measurement (Exercise 6), but now use Exercise 7 to make a period measurement.

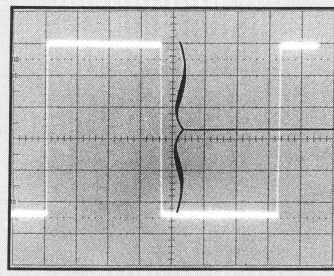
Exercise 6. AMPLITUDE MEASUREMENTS

1. *Connect your probe to the CH 1 connector and attach the tip to the PROBE ADJUST terminal. Attach the probe ground lead to the collar of the CH 2 connector. Make sure your probe is compensated and all variable (CAL) controls are in their detents.*

2. *Set the VERTICAL MODE switch to CH 1 and the channel 1 input coupling switch to AC. The TRIGGER MODE switch should be set to NORM—for normal triggering—and the TRIGGER SOURCE switch set to CH 1.*

3. *Use the TRIGGER LEVEL control to obtain a stable trace and move the CH 1 VOLTS/DIV switch until the probe-adjustment square wave is about five divisions high. Now turn the SEC/DIV switch until about one cycle of the waveform is on your screen. The settings should be 0.1 V (10X PROBE) on the VOLTS/DIV switch and 0.1 ms on the SEC/DIV switch.*

4. *Now use the channel 1 POSITION control to move the square wave so that its bottom is aligned with a convenient horizontal graticule line that lets you approximately center the waveform vertically. Use the HORIZONTAL COARSE POSITION control to move the signal so that either the top or the bottom of one cycle intersects the center vertical graticule line.*



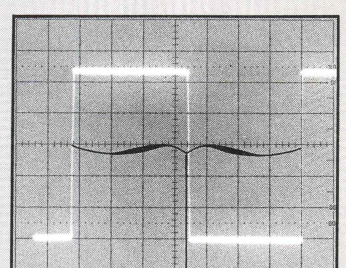
Make Amplitude Measurements On The Center Vertical Graticule Line

5. *You now can make the measurement. Count major and minor divisions up the center vertical graticule line and multiply by the VOLTS/DIV setting. For example, 5.4 divisions times 0.1 V per division equals 0.54 V. If the voltage of the probe adjustment square wave in your scope is different from this example, that's because this signal is not a critical part of your scope and tight tolerances with exact calibration are not required.*

Exercise 7. TIME MEASUREMENTS

Time measurements are best made with the center horizontal graticule line. In this exercise, to make a period measurement, use the existing instrument settings from Exercise 6. Then, with the HORIZONTAL COARSE and FINE POSITION controls, line up one rising edge of the square wave with the graticule line that's second from the left side of the screen. Make sure that each rising edge intersects the center horizontal graticule line.

Count major and minor divisions across the center horizontal graticule line from left to right as shown in the photo. Multiply by the SEC/DIV setting; for example, 7.2 divisions times 0.1 ms per division equals 0.7% ms. If the period of the probe adjustment square wave in your scope is different from this example, remember that this signal is not a critical part of the calibration of your scope.



Make Time Measurements on the Center Horizontal Graticule Line

Frequency and Other Derived Measurements

The voltage and time measurements you just made are two examples of *direct measurements*. Once you've made a direct measurement, you can calculate *derived measurements*. Frequency, derived from period measurements, is one example. While period is the length of time required to complete one cycle of a periodic waveform, frequency is the number of cycles that take place in a second. The measurement unit is hertz (one cycle per second) and it's the reciprocal of period. So a period of 0.001 second (or 1 ms) has a frequency of 1000 Hz (or 1 kHz).

More examples of derived measurements are the alternating-current measurements illustrated in Figure 25.

The following table is a convenient reference for calculating the four main waveform parameters.

Phase Measurements

You know that a waveform has phase, the amount of time that has passed since the cycle began, measured in degrees. Waveforms can also be related by phase shift, and there are two ways to measure it. The first way to measure phase shift between two waveforms is to connect one waveform to each vertical input of a dual channel scope and view them directly either in the chopped or in the alternated vertical mode. Trigger on the channel containing the reference signal. Adjust the TRIGGER LEVEL control for a stable display and measure the waveform period. Adjust the sweep speed so that you have a display similar to the second drawing in

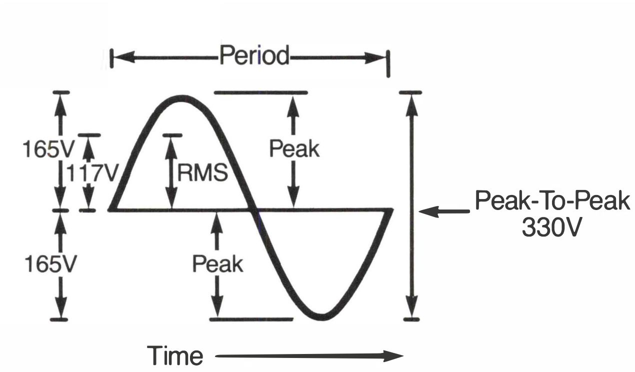


Figure 25. DERIVED MEASUREMENTS are the result of calculations after making direct measurements. For example, alternating current measurements first require an amplitude measurement. The easiest place to start is with a peak-to-peak amplitude measurement of the voltage—in this case, 330 volts—because peak-to-peak measurements ignore positive and negative signs. The *peak voltage* is one-half that value (when there is no DC offset), and is also called *maximum value*; in this case it's 165 V. The *average value* is the total area under the voltage curves divided by the period in radians; in the case of a sine wave, the average value is zero because the positive and negative values are equal. But in some applications such as power, the average value is determined to be:

$$V_{avg} = 0.318 \times V_{p\text{-}p}$$

The rms (root-mean-square) voltage for this sine wave—which represents the line voltage in the United States—is:

$$V_{rms} = \frac{V_p}{\sqrt{2}} = \frac{165}{1.414} = 117 \text{ V}$$

You get from peak-to-peak to rms voltage with:

$$V_{rms} = \frac{V_{p\text{-}p}}{2\sqrt{2}}$$

CALCULATING WAVEFORM PARAMETERS

To Calculate This Amplitude	Multiply This Known Value	By This Conversion Factor
RMS	AVG	1.110[a] 2.220[b]
	PEAK	0.707
	P-P	0.354
AVG	RMS	0.900[a] 0.450[b]
	PEAK	0.637
	P-P	0.318
PEAK	RMS	1.414
	AVG	1.570
	P-P	0.500
P-P	RMS	2.828
	AVG	3.140
	PEAK	2.000

[a] For full-wave rectification
[b] For half-wave rectification

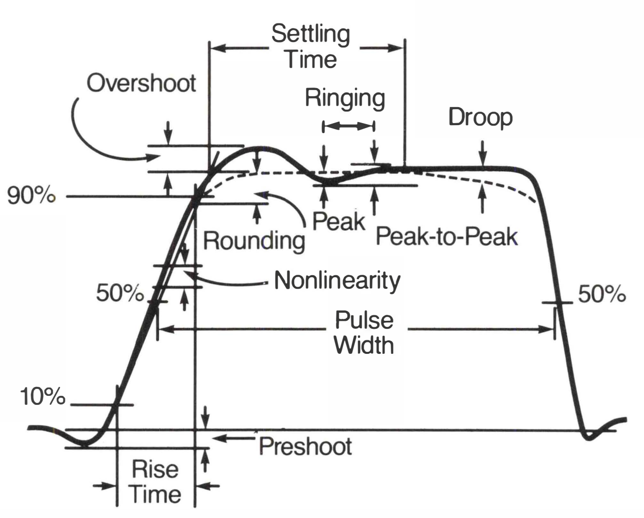


Figure 26. REAL PULSE MEASUREMENTS include a few more parameters than those for an ideal pulse. You'll find several in the diagram above. *Preshoot* is a change of amplitude in the opposite direction that precedes the rising step. *Overshoot* and *rounding* are changes that occur after the initial transition. *Ringing* is a series of amplitude changes—usually a damped sinusoid—that follows the front corner. All are expressed as percentages of amplitude. *Settling time* expresses how long it takes the pulse to stabilize at its maximum amplitude. *Droop* is a decrease in the maximum amplitude with time. *Nonlinearity* is any variation from a straight line drawn through the 10% and 90% points of a transition.

Figure 23. Then measure the horizontal distance between the same points on the two waveforms. The phase shift is the time difference between the points divided by the waveform period, then multiplied by 360 to give degrees.

The second way to measure phase shift is to obtain a Lissajous pattern. Notice that the CH 1 and CH 2 vertical input connectors also are labeled X and Y respectively and that the last position on the SEC/DIV switch is X-Y. This X-Y setting disables the scope's time base. When X-Y is selected, the channel 2 input signal is still the vertical axis of the scope's display, but now the channel 1 signal becomes the horizontal axis.

In the X-Y mode, with one sinusoidal waveform on each channel, your screen displays a Lissajous pattern (named for French physicist Jules Antoine Lissajous and pronounced *LEE-sa-zhoo*). The shape of the pattern indicates the phase shift between the two signals. Some examples of Lissajous patterns are shown in Figure 27.

Note that Lissajous measurements with general-purpose oscilloscopes are usually limited by the frequency response of the horizontal amplifier (typically designed with a far lower bandwidth than vertical channels). Specialized X-Y scopes or monitors have almost identical vertical and horizontal systems.

Exercise 8. DERIVED MEASUREMENTS

With the period measurement you made in Exercise 7, calculate the frequency of the probe adjustment square wave. For example, if the period you measured is 0.72 ms, then the frequency is the reciprocal:

$$f = \frac{1}{T} = \frac{1}{0.00072\ s}$$
$$= 1389\ Hz$$
$$= 1.389\ kHz$$

Other derived measurements you can make are duty cycle, duty factor, and repetition rate. Duty cycle is the ratio of pulse width to signal period expressed as a percentage: 0.5 ms divided by 1 ms, or 50%. (But you knew that; it's always 50% for square waves.) Duty factor, though, is 0.5. The repetition rate describes how often a pulse train occurs. For square waves, repetition rate and frequency are equal. Your probe adjustment signal might differ slightly from this example; if so, calculate the duty cycle, duty factor, and repetition rate for it. You can also calculate the peak, peak-to-peak, and average voltages of the probe-adjustment square wave in your scope. Remember that you need both the alternating and direct components of the signal to make these measurements, so be sure the input coupling switch on the vertical channel you're using is set to DC.

Use the directions in Exercise 9 to make a pulse-width measurement on the probe-adjustment square wave.

Exercise 9. PULSE WIDTH MEASUREMENTS

To measure the pulse width of the probe-adjustment square wave quickly and easily, set your scope to trigger on and display channel 1. Your probe should still be connected to the CH 1 BNC connector and the PROBE ADJUST terminal from the previous exercises. Use a SEC/DIV setting of 0.1 ms with HORIZONTAL MODE at X1; use P-P AUTO triggering on the positive-going (⎍) slope. Adjust the TRIGGER LEVEL control to get as much of the leading edge on screen as possible. Switch the CH 1 input coupling to GND and center the baseline on the center horizontal graticule line. Now switch to AC coupling, because that will center the signal on the screen and let you make a pulse-width measurement at the 50% point of the waveform. Use the HORIZONTAL COARSE and FINE POSITION controls to line up the 50% point with the first graticule line from the left side of the screen. Now you can count divisions and subdivisions across the center horizontal line until you reach the falling edge. Then multiply that value by the SEC/DIV switch setting to find the positive half pulse width. Switch the TRIGGER SLOPE switch to the falling edge (⎍). Repeat the same measurement process to find the negative-half pulse width.

X-Y Measurements

Finding the phase shift of two sinusoidal signals with a Lissajous pattern is one example of an X-Y measurement. The X-Y capability can be used for other measurements as well. Lissajous patterns can also be used to determine the frequency of an unknown signal when you have a known signal on the other channel. This is a very accurate frequency measurement as long as the known signal is accurate and both signals are sine waves. The patterns you can see are illustrated in Figure 27, where the effects of both frequency and phase difference are shown.

Component checking in a service or production situation is another X-Y application and requires only a simple transformer circuit like the one shown in Figure 28.

You'll find many other applications for X-Y measurements in televison servicing, engine analysis, two-way radio servicing, and more. Any time you have physical phenomena that are interdependent and not time-dependent, X-Y measurements are the answer. Aerodynamic lift and drag, motor speed and torque, or pressure and volume of liquids and gasses are more examples. With the proper transducer, you can use your scope to make any of these measurements.

Differential Measurements

The ADD and the CH 2 INVERT VERTICAL MODE functions on your 2225 Oscilloscope allow you to make differential measurements. Often differential measurements permit eliminating undesirable components from a signal. If you have a signal that's very similar to the unwanted noise, the setup is simple. Put the signal with the spurious information on channel 1. Connect the signal that is like it, but with unwanted components, on channel 2. Set both input coupling switches to DC (use AC if the DC components of the signal(s) are too large) and select a dual channel vertical mode by moving the VERTICAL MODE switches to BOTH-ALT (or CHOP, depending on signal frequency).

Now set both VOLTS/DIV switches so that the noise components of the two signals are about equal in amplitude. Then you can move the right VERTICAL MODE switch to ADD and the middle switch to CH 2 INVERT so that the common-mode signals have opposite polarities.

If you use the CH 2 VOLTS/DIV switch and its CAL control for maximum cancellation of the common signal, the trace that remains on screen will contain only the desired part of the channel 1 input signal. The two common-mode signals have cancelled each other out, leaving only the difference between the two. An example is shown in Figure 29.

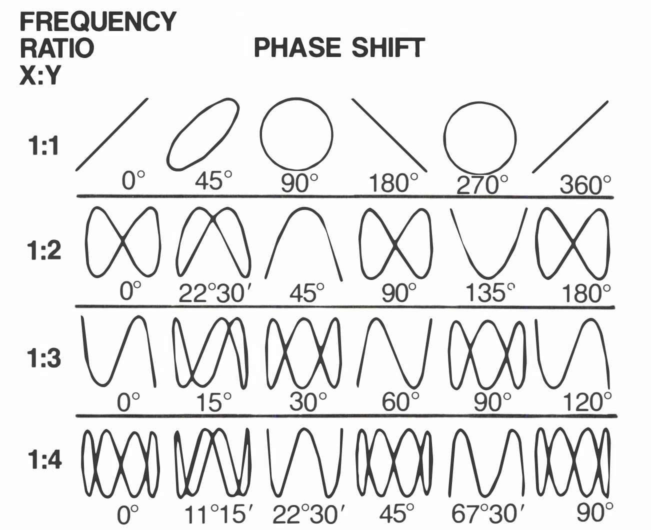


Figure 27. FREQUENCY MEASUREMENTS WITH LISSAJOUS PATTERNS require a known sine wave on one channel. If there is no phase shift, the ratio between the known frequency (usually applied to the X input) and the unknown frequency (applied to the Y input) corresponds to the ratio between the number of vertical loops and the number of horizontal loops in the pattern. When the frequencies are the same, only the shifts in phase affect the pattern. In the drawings here, both phase and frequency differences are shown.

Using the Z-Axis

Remember from Part I that the crt has three axes of information: X is the horizontal axis, Y is the vertical axis, and Z is the intensity axis. The Z-axis input lets you change the brightness of the signal on the screen with an external signal. On the 2225, the Z-axis input will accept a signal of up to 400 V (dc + peak ac) through a usable frequency range of DC to 5 MHz. Positive voltages decrease brightness and negative voltages increase it; 5 V causes a noticeable change.

The Z-axis input is an advantage to users who have set up their instruments for a long series of tests. One example is the testing of high-fidelity equipment illustrated by Figure 30.

TV Triggering

The NTSC composite-video waveform consists of two fields, each containing 262½ lines. Many scopes offer television triggering to simplify viewing video signals. Usually, however, the scope will only trigger on fields at some sweep speeds and on lines at others. The 2225 will let you trigger on either lines or fields at any sweep speed.

To look at TV fields with a 2225 Oscilloscope, use the TV FIELD TRIGGER MODE.

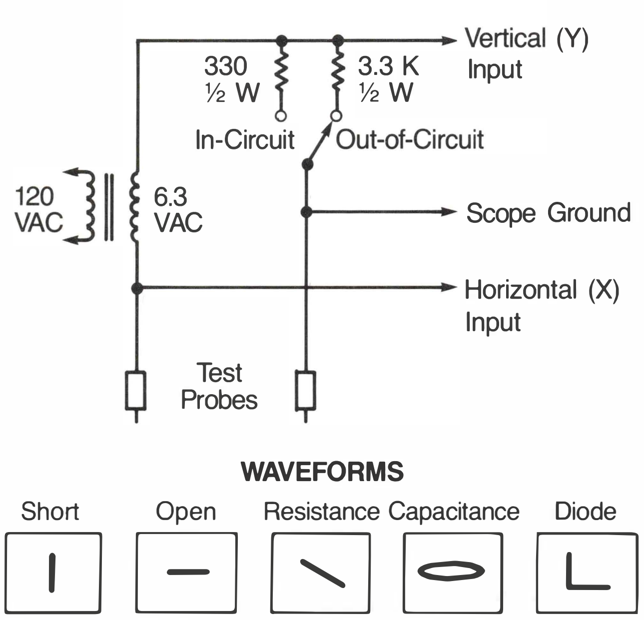


Figure 28. X-Y COMPONENT CHECKING requires the transformer circuit shown above. With it connected to your scope and the scope in the X-Y mode, patterns like those illustrated indicate the condition of the component. The patterns shown can be seen when the components are tested out of the circuit; in-circuit component patterns differ because of resistors, capacitors, and other devices connected to the component under test.

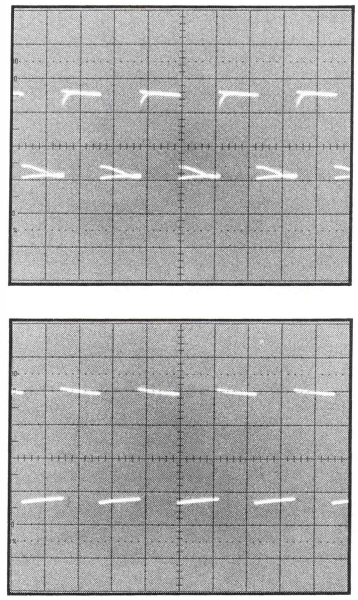


Figure 29. DIFFERENTIAL MEASUREMENTS allow you to remove unwanted information from a signal any time you have another signal that closely resembles the unwanted components. For example, the first photo shows a 1-kHz square wave contaminated by a 60-Hz sine wave. Once the common-mode component (the sine wave) is input to channel 2 and that channel is inverted, the signals can be added by selecting ADD VERTICAL MODE. The result is shown in the second photo.

This mode allows the scope to trigger at the field rate of the composite video signal on either field 1 or field 2. Since the trigger system cannot recognize the difference between the two fields, it will trigger alternately on them. The display will be confusing if you look at one line at a time.

To prevent this, add more holdoff time using one of two methods. Either use the HOLDOFF control, or simply switch the VERTICAL MODE to display BOTH channels. That makes the total holdoff time for one channel greater than one field period. Then position the unused vertical channel off-screen to avoid confusion.

It is also important to select the trigger slope that corresponds to the edge of the waveform where the sync pulses are located. Picking a negative slope for triggering on TV sync signals will show as many sync pulses as possible.

When you want to observe the TV line portion of the composite video signal, use the TV LINE TRIGGER MODE and get a stable display by triggering on the horizontal synchronization pulses. It is usually best to select the blanking level of the sync waveform so that the vertical field rate will not cause double triggering.

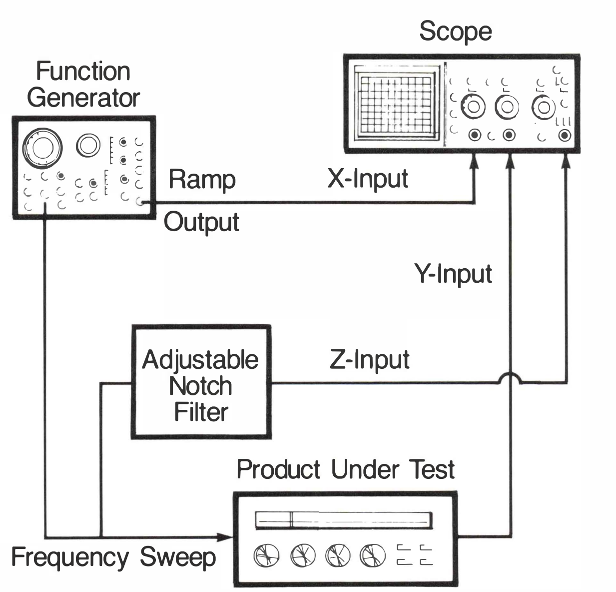


Figure 30. USING THE Z-AXIS can provide additional information on the scope screen. In the setup drawn above, a function generator sweeps through the frequencies of interest during product testing—20 Hz to 20,000 Hz, in this case. Then an adjustable notch filter is used to generate a marker—at 15 kHz, for instance—and this signal is applied to the Z-axis input to brighten the trace. This allows the tester to evaluate product performance at a glance.

Waveform Expansion for Detailed Analysis

The unmagnified sweep—that's the trace you see when HORIZONTAL MODE is set to X1—is the horizontal function you'll need for most applications. Best measurement accuracy is achieved by setting the SEC/DIV control for the fastest sweep that will display the interval of interest. And remember that the variable control (CAL) should be in its detent (fully clockwise).

On the 2225, there are also two magnified modes, ALT and MAG. These modes take the measurement of time a step further. Because they expand the unmagnified trace (that is, the *normal* trace), the ALT and MAG modes give you the ability to make a variety of measurements that previously were only possible on scopes having dual time bases. These include measurements such as digital system timing, television signal analysis, and waveform comparisons.

When ALT is chosen, both the normal and the magnified waveforms appear together on the crt screen. Since you can use the 2225 Oscilloscope to display the normal and the magnified waveforms from both channel 1 and channel 2, it's possible to have four traces on the crt screen at one time.

To prevent overlapping traces in this situation, there is an additional position control—labeled TRACE SEP—which adjusts the vertical separation between the normal and the magnified traces. By using the TRACE SEP control together with the two VERTICAL POSITION controls, you can place all four traces on the screen without confusion.

When MAG is selected, only the magnified trace is displayed on the screen. This is useful for eliminating unwanted clutter from the crt when you are making accurate time measurements or are looking at waveform details.

In either ALT or MAG MODE, the amount of waveform expansion is determined by the setting of the HORIZONTAL MAG switch located beneath the SEC/DIV control. Three magnifications are selectable—5X, 10X, and 50X. Magnification increases the sweep speed by the set amount without changing the basic SEC/DIV setting. For example, if the SEC/DIV control were set to 50 μs, with ALT MODE chosen and 10X MAG selected, the sweep speed of the magnified trace would be 5 μs per division. Having the ability to select various combinations of waveform expansion and SEC/DIV control settings lets you extend the timebase range out to a maximum of 5 ns per division.

The registration marker that links the timing of the normal and the magnified traces with each other is the center vertical graticule line. The intersections of that line with the normal and the magnified waveforms represent the same point in time (from sweep start) on both traces. With the center vertical graticule as the reference line, you have the ability to investigate waveform details around any point you choose on the normal trace. And because it's expanded, the magnified waveform makes your time measurement easier to perform as well as enhances the precision.

Using the Horizontal Magnification Modes

Often the magnification modes ALT and MAG can be used to enhance the precision of a particular measurement such as rise time—especially for faster pulses. The measurement in Exercise 10 is a good example. Making an accurate assessment of rise time on these pulses would be a more difficult task if the alternate magnification feature were not available. This is because the transition edge of interest could not be expanded enough along the time axis so that it occupies two or more divisions.

Using the horizontal magnification modes on the Tektronix 2225 Oscilloscope for making time measurements is a simple technique that is easily learned. Generally, the steps are: (1) display the waveform in X1 HORIZONTAL MODE at the fastest sweep speed that shows the area you wish to inspect, (2) use the COARSE POSITION control to move the area of interest to the center vertical graticule line, (3) switch HORIZONTAL MODE to ALT, and (4) set the MAG switch to the highest magnification that completely shows the area of interest on the screen.

At this point you can either leave the MODE switch at ALT or set it to MAG, depending on the particular measurement to be made and the amount of distracting clutter you wish to remove from the screen. Switching to MAG causes the normal (unmagnified) trace to disappear. Then align the magnified trace to the desired point (using the FINE POSITION control) and make your time measurement on the magnified waveform.

Expanding the trigger point is another example that demonstrates the usefulness of the horizontal magnification modes. Just set the beginning of the normal trace to the center vertical graticule line and select ALT

Then expand the magnified trace an appropriate amount (X5, X10, or X50). With this technique, you can view the trigger point in greater detail and adjust the trigger level to exactly where you want it.

Figure 31 shows the front-panel controls associated with the horizontal magnification function, and Figure 32 illustrates two measurement applications.

High Sensitivity and Vertical Expansion

Besides horizontal magnification, there's also a vertical magnification function. It is initiated by pulling the VOLTS/DIV CAL (X10 PULL) knob out towards you. Vertical magnification expands the waveform amplitude and increases the sensitivity of the active setting on the VOLTS/DIV switch by a factor of 10. For the 5 mV per division setting on the 2225, vertical magnification increases sensitivity to a maximum of 500 μV per division. This function is especially helpful for triggering on, displaying, and making measurements on low-level signals.

Typical applications in which vertical magnification can improve voltage measurement resolution involve those that employ transducers and similar sensors. Transducers are devices that generate small electrical signals proportional to the physical phenomena being observed. For example, fluctuations detected by a pressure transduces are converted to voltages that correspond to the pressure levels. These low-level signals then are applied to the input connectors of the oscilloscope and displayed on the crt.

Other applications in which vertical magnification is useful include the measurement of power-supply ripple. Ripple is the portion of a supply's output voltage that is harmonically related in frequency to the input power and to any internally generated switching frequency. And vertical magnification is also an effective function for measuring noise and common-mode rejection ratio.

When X10 vertical magnification is activated on a particular input channel, bandwidth on that channel is reduced to 5 MHz. Bandwidth limiting is effective in eliminating or reducing unwanted high-frequency noise components that may be present on an input signal. Since this function can be independently selected on channel 1 and channel 2, you therefore have the ability to limit the bandwidth on one channel without affecting the bandwidth on the other channel. Independent bandwidth limiting of each input channel gives you greater versatility when you are comparing two different signals.

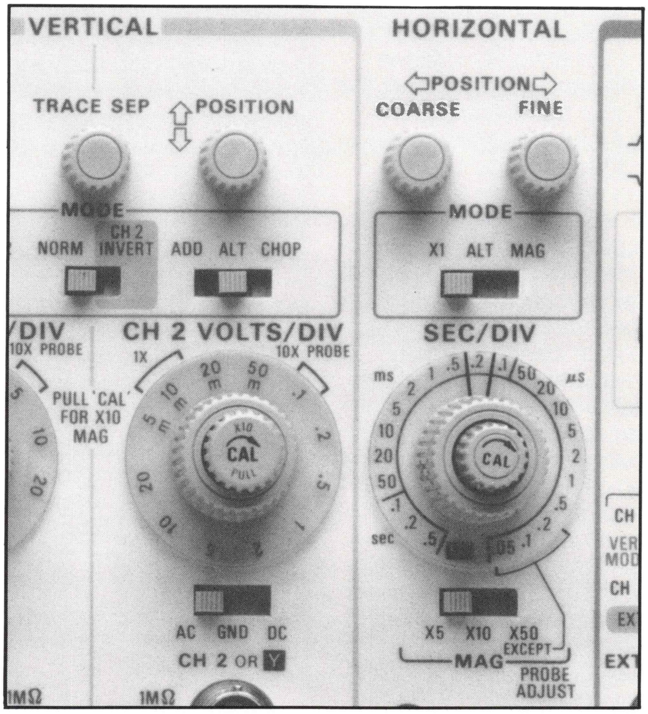


Figure 31. THE HORIZONTAL MAGNIFICATION CONTROLS on the 2225 Oscilloscope are shown in this photograph. They include: COARSE and FINE POSITION (top right); MODE (X1-ALT-MAG); SEC/DIV; and MAG (X5-X10-X50). One other control associated with the horizontal magnification function is TRACE SEP (top left). It moves the magnified trace vertically with respect to the unmagnified trace.

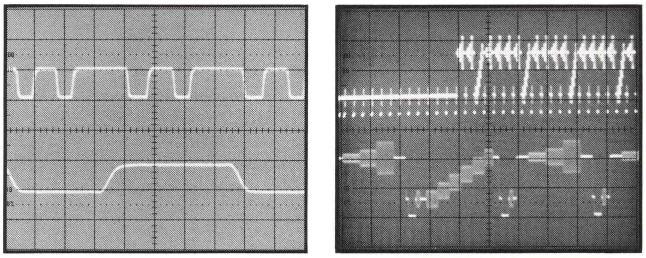


Figure 32. HORIZONTAL ALTERNATE MAGNIFICATION MEASUREMENTS are fast and simple to make. One use, examining timing in a digital circuit, is demonstrated in the left photograph. Suppose you need to check the width of one pulse in a pulse train like the one shown. To make sure you are measuring the correct pulse, you must look at a large portion of the signal. But to measure one pulse accurately, you need a faster sweep speed. Looking at the big picture simultaneously with an enlargement of a small part of the signal is a simple task with the horizontal alternate magnification feature. A second example is shown in the right photograph. Here, triggering is on one field of a composite video signal—displayed by the top (unmagnified) waveform. The bottom (magnified) waveform was attained by setting ALT HORIZONTAL MODE and X50 MAG. With the COARSE and FINE POSITION controls you can walk through the field and look at each line individually.

There are other advantages in using the X10 vertical magnification function to limit bandwidth. It lowers the trigger bandwidth, which reduces unwanted noise triggering. Thus it gives you more stable triggering on low-level signals—especially those less than 5 mV p-p. Using X10 vertical magnification also lets you continue using a high-input-resistance 10X probe for measuring low-level signals instead of a 1X probe. Because the 10X probe has much less loading effect on the circuit under test than a 1X probe, the displayed signal is a more faithful reproduction of the actual input signal, and any measurements you make will naturally be closer to what is really happening in the circuit under test.

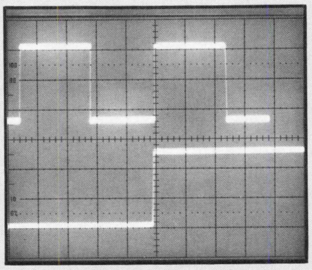
Practice Measurements

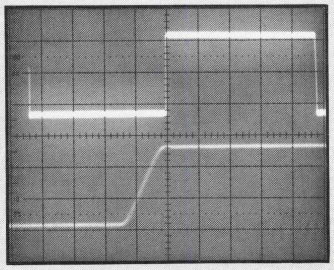
Having the ability to view a signal at two different sweep speeds makes time measurement easier. The normal trace shows you a large slice of time on the signal being examined. And the magnified trace—the one with the faster sweep speed—expands the normal waveform to allow inspection of any portion in greater detail. You'll find this capability useful in many measurement applications.

This discussion should have started you thinking about other uses for the magnified modes on the 2225 Oscilloscope. Now it's time to practice. As you use the scope for Exercise 10, you'll find that the procedure is very easy to perform.

Note: Alt. Magnification on the 2225 places the magnified trace above the non-magnified trace, which is opposite from what is shown in exercise 10.

Exercise 10. MEASUREMENTS USING HORIZONTAL ALTERNATE MAGNIFICATION





Rise Time

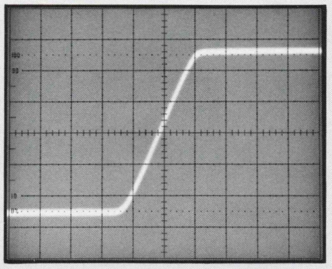
1. *Connect your probe to the CH 1 connector and attach the probe tip to the PROBE ADJUST terminal. Hook the ground strap onto the collar of the CH 2 BNC connector and make sure the probe is compensated for channel 1.*

2. *Use these control settings: VERTICAL MODE to CH 1; CH 1 VOLTS/DIV to 0.2 (10X PROBE); CH 1 variable in CAL detent and pushed in (no vertical magnification); CH 1 input coupling to AC; HORIZONTAL MODE to X1; SEC/DIV to 0.1 ms and its variable control in CAL detent; MAG to X5; TRIGGER SLOPE to the falling edge ( ); MODE to P-P AUTO; SOURCE to either CH 1 or VERT MODE; and COUPLING to AC.*

3. *If necessary, adjust the TRIGGER LEVEL control for a stable display, then position the waveform in the upper half of the screen. Switch the HORIZONTAL MODE to ALT and use the TRACE SEP control to move the magnified sweep to the lower half of the screen.*

4. *With the COARSE and FINE POSITION controls, place the rising edge of a pulse on the upper (unmagnified) trace and the rising edge of the corresponding pulse on the lower (X5 magnified) trace along (or nearly along) the center vertical graticule line. Recall that the center vertical graticule line is the registration mark representing the same point in time (from the start of the sweep) along both the unmagnified and the magnified traces. Now your screen should look like the first photo.*

5. *Increase the sweep speed a step at a time by*



rotating the SEC/DIV switch clockwise; stop when there is one complete rising edge remaining on the upper trace. For this particular signal, the setting should be 50 µs. Again, align the rising edges of both traces to the center vertical graticule line. Then, while watching the lower trace, switch MAG to X10 and to X50; notice what happens to the rising edge in the magnified trace. Your screen should look like the second photo.

6. *Eliminate the upper trace by switching MODE to MAG. Use the TRACE SEP control to center the waveform vertically. Set the CH 1 VOLTS/DIV switch to 50 mV (10X PROBE), then rotate its variable control counterclockwise out of detent. Use that control alternately with the TRACE SEP control to obtain an exact 5-division display with the zero reference aligned to the 0% graticule line and the maximum value aligned to the 100% graticule line.*

7. *Adjust the FOCUS and INTENSITY controls for a sharp, bright trace and then position the waveform so that it intersects a vertical graticule line at the 10% marking. Now your screen should look like the third photo.*

8. *Count the horizontal divisions between the points where the waveform crosses the 10% and 90% markings. In this example, it's 1.7 divisions. To calculate the rise time, multiply this measured distance by the SEC/DIV switch (50 µs per division), then divide the product by the magnification factor (50). Your answer should be a rise time of 1.7 µs.*

9. *One last word on rise-time measurements. The accuracy of the measurement you make depends on both the human visual error and the performance of your scope. In the next section, you'll find a description of how the scope's own rise time affects measurement results.*

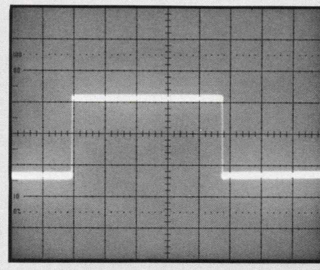
Pulse Width

1. *Perform steps 1 through 3 in the preceding rise-time measurement exercise. Switch HORIZONTAL MAG to X10.*

2. *Decrease the sweep speed a step at a time by rotating the SEC/DIV switch counterclockwise; stop when there is at least one complete pulse (one half of a cycle) on the lower trace. For this particular signal, the setting should be either 0.5 ms or 1 ms, depending on the exact signal frequency in the oscilloscope you're using. Eliminate the upper trace by switching MODE to MAG.*

3. *Switch the channel 1 input coupling to GND. Use the TRACE SEP control to align the baseline trace exactly on the center horizontal graticule line, and then switch input coupling back to AC. This centers the waveform vertically.*

4. *With the COARSE and FINE POSITION controls, horizontally move the pulse to be measured so that its left-most edge intersects a convenient calibration mark on the center horizontal graticule line (see photo). This step*



properly positions the pulse on the screen so that the pulse width can be measured at the 50% amplitude level.

5. *Count the horizontal divisions (along the center horizontal graticule line) between the two pulse edges. In this example, it's 4.8 divisions. To calculate the pulse width, multiply this measured distance by the SEC/DIV switch setting (1 ms per division), then divide the product by the magnification factor (10). Your answer should be a pulse width of 0.48 ms.*

SCOPE PERFORMANCE

There are two aspects to oscilloscope performance: the design parameters of the instrument and its conformance to those parameters at the time you are making measurements. Making the instrument conform to its design parameters simply means calibration—including making sure the probe is properly compensated as you've done many times already. But even with proper calibration, the designed performance will have some effect on your measurements.

Square-Wave Response and High-Frequency Response

The design of amplifiers, like those in a scope's vertical channels, involves some compromise between the circuit's high frequency response and its handling of signals with square transitions. The frequency response can be extended with high frequency compensation. But too much compensation results in overshoot on a step, and too little extends the measured rise time. The best rise times without overshoot are achieved when the high-frequency response is critically damped, causing the frequency response to fall off smoothly. Figure 33 illustrates the effects of high-frequency compensation.

Instrument Rise Time and Measured Rise Time

The rise time of an oscilloscope is a very important specification, because its rise time affects the accuracy of the rise times it measures, as expressed by this approximation:

$$t_{r(measurement)} = \sqrt{t_{r(signal)}^2 + t_{r(system)}^2}$$

In practical terms this means that the accuracy of a measured signal is predictable and depends on how much faster your scope is than the rise times you're measuring. If the scope is five times faster than the signal, the measurement error can be as low as 2%. For measurement accuracies of 1%, you will need a scope seven times faster than the signal it measures, as shown in the chart in Figure 34.

Bandwidth and Rise Time

The vertical channels of an oscilloscope are designed for a broad bandpass, generally from some low frequency (dc) to a much higher frequency. This is the oscilloscope's bandwidth, specified by listing the frequency at which a sinusoidal input signal is attenuated to 0.707 of the lower reference frequencies — the −3 dB point. For older instruments, specifications cited both a low and a high −3 dB point. Modern instruments, however, have a relatively flat frequency response down to 0 Hz (dc), so only the upper number is quoted as the bandwidth.

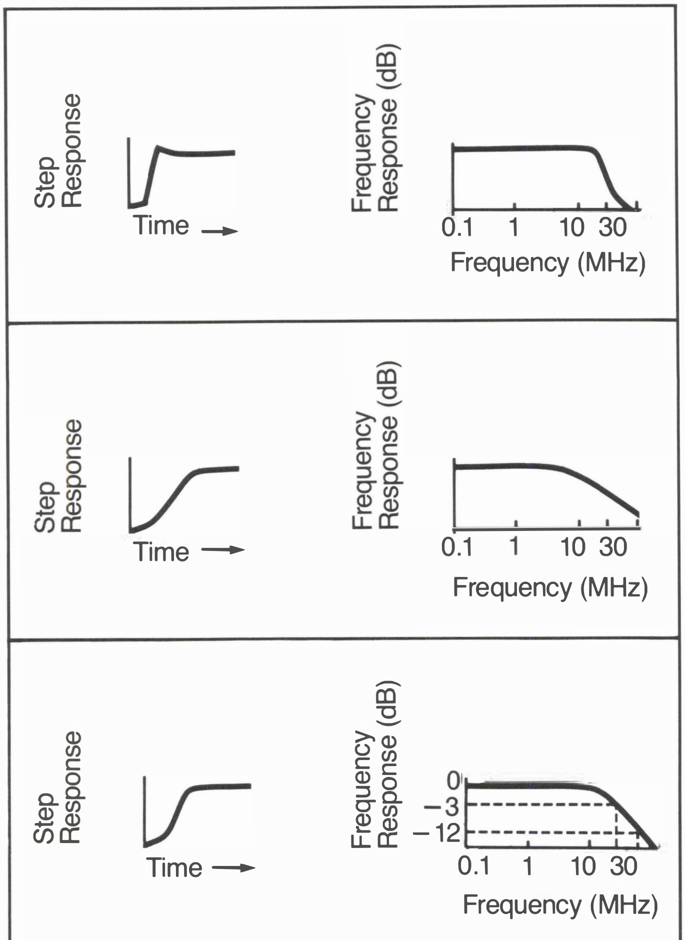


Figure 33. HIGH-FREQUENCY COMPENSATION in a vertical amplifier affects the rise time of square waves measured by the scope. With too much high-frequency compensation, the rise times will show overshoot and possible ringing, as in the top drawing. With too little, as shown in the second drawing, the rise times roll off the edges of the square wave. A critically damped frequency response is best, as in the third drawing.

A bandwidth specification gives you an idea of the instrument's ability to handle high-frequency signals within a specified attenuation. But bandwidth specifications are derived from the instrument's ability to display sine waves. A 35 MHz scope will show a 35 MHz sine wave with only −3 dB attenuation, but the effects on a square wave at or near the scope's upper bandwidth limit will be much more severe, because high-frequency information in the

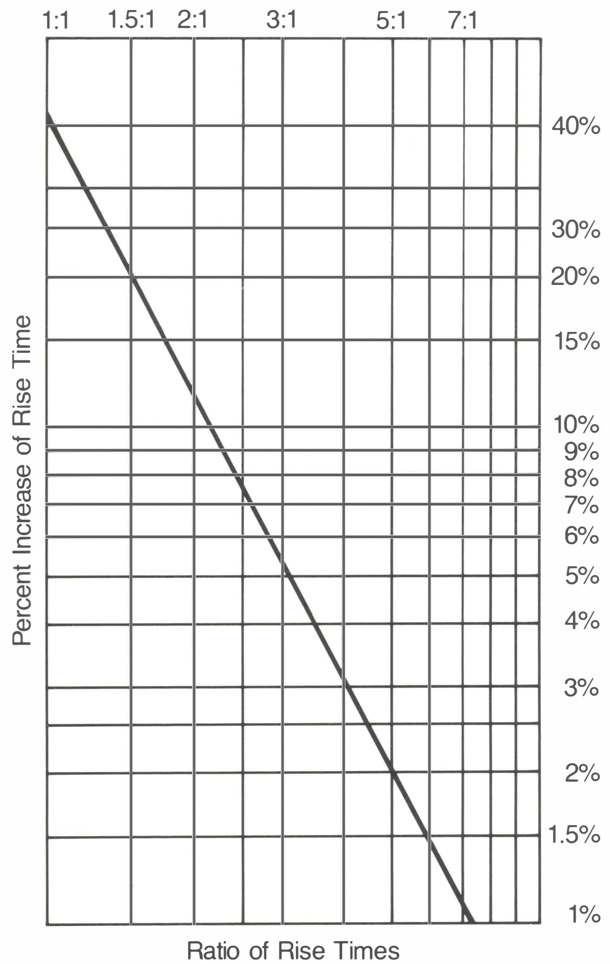
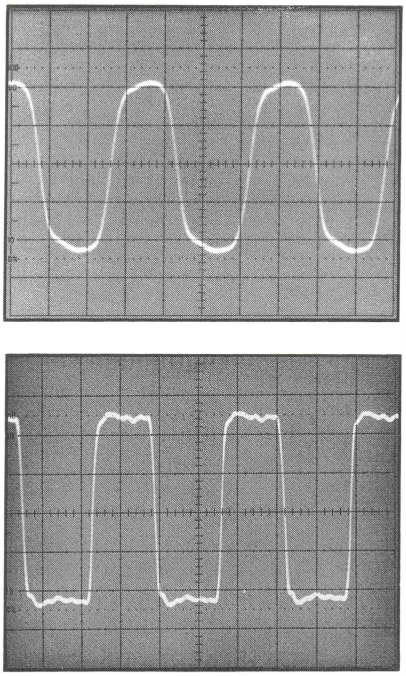


Figure 34. MEASURED RISE-TIME ERRORS depend on the ratio of the scope's rise time to the actual rise time of the signal being measured. As you can see from the graph, when the scope is five times faster, the error is a 2% increase in measured rise time. If the rise times are equal, the error increases to 41%.

square wave cannot be accurately reproduced by the scope. See Figure 34 for an example.

The frequency response of most scopes is designed with a constant that lets you relate the bandwidth and rise time of the instrument. This constant is 0.35, and the rise time and bandwidth are related by this approximation:

$$t_r = \frac{0.35}{BW}$$



15-MHz Square wave on a 35 MHz Oscilloscope

15-MHz Square wave on a 50 MHz Oscilloscope

Figure 35. BANDWIDTH SPECIFICATIONS are based on the scope's ability to reproduce sine waves. The upper bandwidth is the frequency at which a sine wave is reduced to 0.707 of the amplitude shown at lower reference frequencies. Though this specification tells you how well the instrument reproduces sine waves, not every signal you examine is sinusoidal. Square waves, for example, have a great deal of high-frequency information in their rising and falling edges that will be lost as you approach the bandwidth limits of the instrument. To illustrate, the two crt photos show a 15-MHz square wave reproduced by a 35-MHz oscilloscope (top) and a 50-MHz oscilloscope (bottom).

A simple way to apply the formula is:

$$t_r(\text{in ns}) = \frac{350}{\text{BW (in MHz)}}$$

For the Tektronix 2225 Oscilloscope with a bandwidth of 50 MHz, the measurement system rise time is 7.0 ns.

CONCLUSION

This concludes your introduction to oscilloscopes and the measurements you can make with scopes. You've done well to progress this far, but this primer can only introduce the concepts and measurement techniques. With practice and experience, you'll find yourself making faster and more accurate measurements. Then you, too, will find that using an oscilloscope becomes second nature. For more information about oscilloscope basics, request a copy of the 2225 Technique Brief series.

GLOSSARY

AC Signal. The time-variant portion of voltage or current.

Alternate Sweep. A vertical mode of operation for a dual-trace oscilloscope. The signal from the second channel is displayed after the signal from the first channel. Each trace has a complete sweep, and the display continues to alternate. This mode is used for SEC/DIV settings of less than 1 ms/div (faster).

Alternating Current (ac). An electric current whose instantaneous value and direction change periodically. The term usually refers to sinusoidally shaped current or voltage waves.

Attenuation. The decrease in signal amplitude during its transmission from one point to another.

Bandwidth. The oscilloscope frequency range within which performance of a particular characteristic falls within specified limits, commonly defined as the difference between the upper and lower frequency at which the response is 0.707 (− 3 decibels) of the response at the reference frequency.

Blanking. The process of making the trace, or parts of a trace, invisible.

Calibration. The process of comparing an instrument or device against a standard to determine instrument accuracy or to make a correction.

Capacitance. That property of a system of conductors and dielectrics which enables the system to store electricity when a voltage exists between the conductors, expressed as the ratio of the electrical charge stored and the voltage across the conductors. The basic unit is the farad.

Capacitor. A device consisting of two conducting materials separated by an insulating material (dielectric), which can store an electrical charge when potential differences exist between the conductors.

Cathode-ray Tube (crt). An electron-beam tube in which the beam can be focused to a small cross section on a luminescent screen and varied in both position and intensity to produce a visible pattern.

Chop. A vertical mode of operation for dual-trace oscilloscopes in which the display is switched between the two channels at some fixed rate. This mode should be used for slow sweep rates.

Common. The potential level which serves as the ground for a given circuit.

Compensation. The controlling elements that compensate for, or offset, the undesirable characteristics of the process being controlled in a system.

Coupling. The association of two or more circuits or systems in such a way that power or information may be transferred from one to the other.

Detent. A stop or other holding device (such as a pin or lever) on a ratchet wheel. Switch action is typified by a gradual increase in force to a position at which there is an immediate and marked reduction in force.

Direct Current (dc). An electric current that flows in only one direction with essentially constant value.

Display. The visual representation of a signal on a crt screen.

Distortion. An undesired change in a waveform.

Dual-channel (Dual-trace) Oscilloscope. An oscilloscope that has two independent input connectors and vertical sections and can display them simultaneously.

Dual-sweep (Dual-time-base) Oscilloscope. An oscilloscope that can display a signal with two independent SEC/DIV settings.

Focus. The oscilloscope control that converges the crt electron beams to produce sharpness of display.

Free-running Trace. A trace that is displayed without being triggered and either with or without an applied signal.

Graticule. The crt grid lines that facilitate the location and measurement of oscilloscope traces.

Ground (GND). 1. A conducting connection by which an electric circuit or equipment is connected to the earth to establish and maintain a reference potential level. 2. The voltage reference point in a circuit.

Hertz (Hz). The unit of frequency, one cycle per second.

Impedance. The total apparent opposition a circuit offers to the flow of alternating current at a given frequency.

Megahertz (MHz). A frequency of one million Hz (cycles per second), or 10^6 Hz.

Noise. An unwanted voltage or current in an electrical circuit.

Oscilloscope. An instrument for making visible the instantaneous values of one or more rapidly varying electrical quantities as a function of time or of another electrical or mechanical quantity.

Probe. An oscilloscope input device, usually having a pointed metal tip for making electrical contact with a circuit element and a flexible cable for transmitting the signal to the oscilloscope.

Rise Time. The time taken for the leading edge of a pulse to rise from 10% to 90% of its final value.

Scope. Shortened form of oscilloscope.

Screen. The surface of the crt upon which the visible pattern is produced, the display area.

Sensitivity. The ratio of the output value to the input value.

Signal. A visual, audible, electrical, or other indication used to convey information.

Single Sweep. The ability of an oscilloscope to display just one window of time, thus preventing unwanted multiple displays. Useful for trace photography.

Slope. The ratio of the change in the vertical quantity (Y) to the change in the horizontal quantity (X).

Spot. The illuminated area that appears where the electron beam strikes the screen of a crt.

Sweep. Time-dependent information created by the electron beam moving across a crt screen.

Time Base. Oscilloscope circuitry that controls the time dependence for the sweep. Time dependence is set by the SEC/DIV control.

Trace. The visual representation of an individual signal on a crt.

Transducer. A device that provides a usable output in response to a specific physical quantity, property, or condition which is measured.

Transient. A phenomenon caused in a system by a sudden change in conditions that persist for a relatively short time after the change.

Trigger. The signal used to initiate the sweep on an oscilloscope and determine the beginning point of the trace.

Trigger Holdoff. A front-panel control that inhibits the trigger circuit from looking for a trigger for some specified time after the end of the trace.

Trigger Level. The instantaneous level that a trigger source signal must reach before a sweep is initiated by the trigger circuit.

Volt. The unit of electric potential difference and electromotive force equal to the difference of potential between two points on a conductor carrying a constant one-ampere current when the power dissipated between these points is equal to one watt.

Voltage. The difference in electric potential, expressed in volts, between two points.

Waveform. Graphic representation of the variation of a quantity (such as volts) as a function of some variable, usually time.

X-Y. A graphic representation of the relationship of the X signal, which controls the horizontal position of the beam in time, and the Y signal, which controls the vertical position of the beam in time.

Z-axis. Refers to the signal in an oscilloscope that controls electron-beam brightness as the trace is formed.

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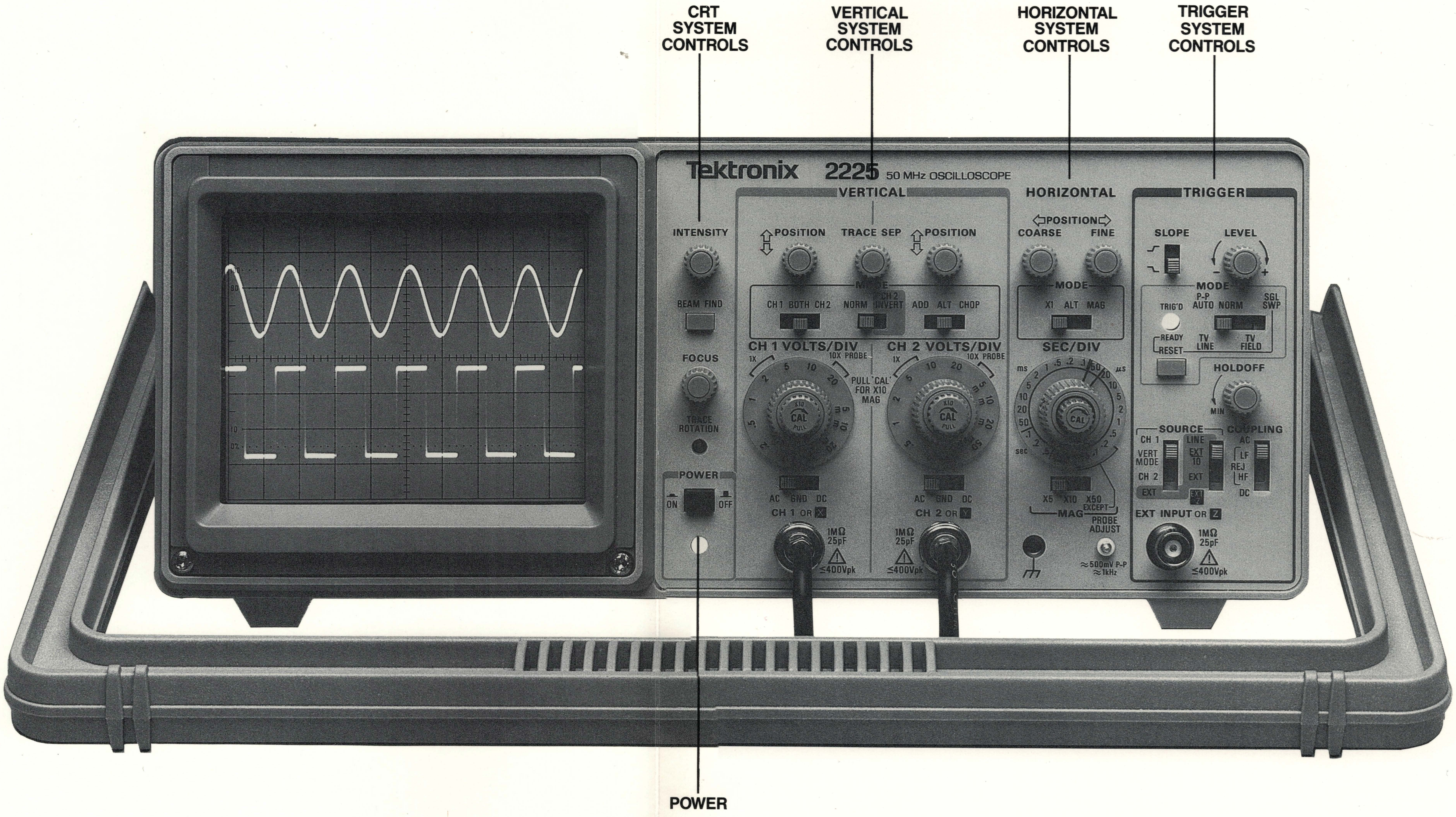
Tektronix was incorporated more than 40 years ago. Since then it has grown to be the largest manufacturer of oscilloscopes in the world. The list of innovations Tek has pioneered includes: triggered sweeps, calibrated time bases, low-loading probes, bistable and fast-transfer storage. Included in Tek's broad measurement offerings are:

- Portable scopes small enough to hold in your hand or fast enough to measure 350 MHz signals.
- Storage scopes (both analog and high-performance digital types) with writing rates as fast as 2500 cm/μs and 14 GHz sampling scopes.
- Modular laboratory scopes as fast as 1 GHz.
- General-purpose plug-in instruments like digital counters and multimeters, functions generators, distortion analyzers, and programmable calibrators.
- IEEE-488 programmable instruments.
- Accessories to support these instruments, including probes, cameras, cables, and scope carts.

Behind all these products is the world-wide Tektronix sales and service organization with 45 offices in the United States and over a hundred offices in 65 other countries around the world.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CH 2 OR Y
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